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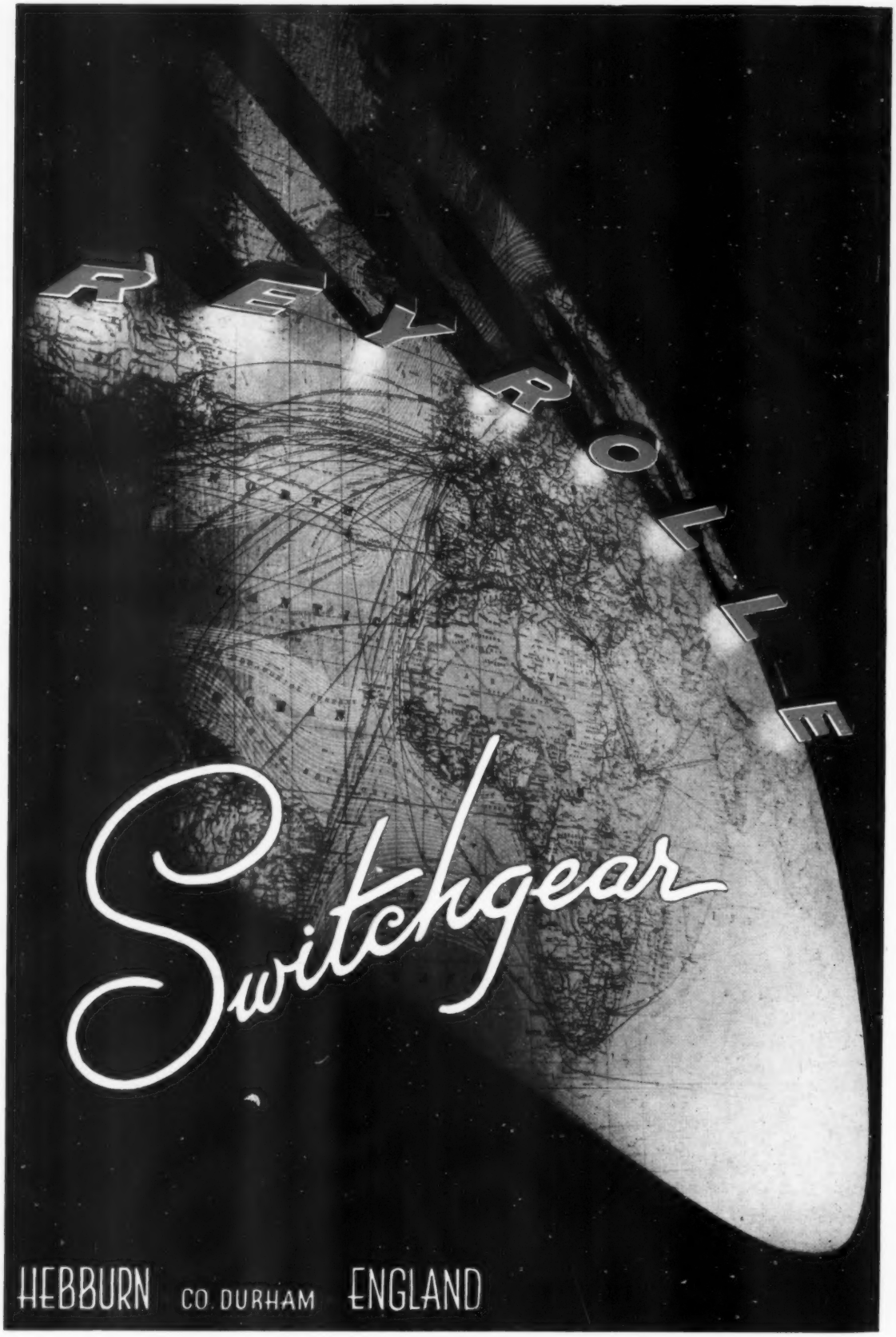
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A technical journal devoted to the study of all aspects of Hydro-electric developments

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POWER FOR LISBON

from the CASTELO do BODE HYDRO-ELECTRIC SCHEME

Terminating Gantry at Castelo do Bode, showing substation and transformer house in background.

CONVEYED BY OVERHEAD TRANSMISSION LINES ERECTED BY

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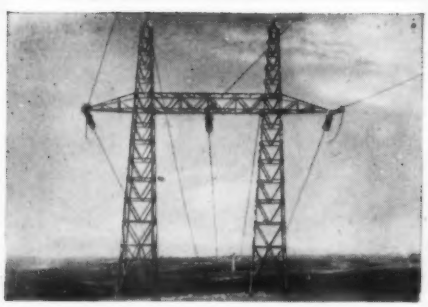

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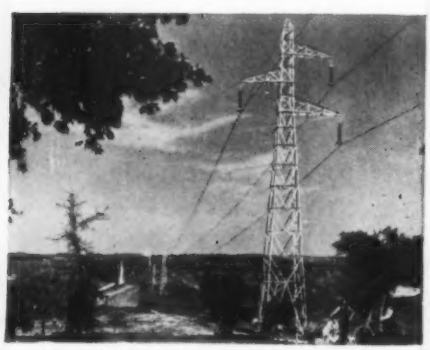

General view of transmission line carried by intermediate type towers.

66 miles of 150 kV overhead lines capable of conveying 60 MW of electric power to the Portuguese capital were erected in 15 months - within the contract completion date.

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WATER POWER

A technical journal devoted to the study of all aspects of Hydro-Electric Development

Prediction

IN almost every exposition of the virtues of power produced by the agency of falling water, there has nearly always appeared a phrase which ran something like this: "Finally, it cannot be too often stressed that a hydro-electric scheme, once established, has a permanent, unchanging supply of fuel."

This principal advantage of water power has been accepted for so long that to question it sounds almost sacrilegious; and yet in the General Report on the Energy Resources and Power Developments since 1924, presented at the Fourth World Power Conference this year, it was stated that "Even the water power situation is not without its question marks. Climatological changes which may or may not be permanent are affecting glacial reserves and precipitation in some parts of the world." Thus a shadow of doubt is cast on the long-vaunted permanence of hydro-electric energy.

Allied to the questions raised by climatic changes is the experience, in recent years, of countries largely reliant on water power. The droughts which have affected water power installations in Italy, France, Spain, New Zealand and Canada, and the serious consequences which have ensued from "dry years," causing great dislocation of industry, prove, if proof were needed, how important it is that the supply of electric power should be continuous not only from hour to hour and day to day, but from year to year, and indeed, from century to century. Brief power cuts due to short term inadequacy of steam plant have given rise to sufficient industrial troubles in Great Britain: the fear of power failures for long periods, in the years to come, is likely to have a restrictive effect on the industrial expansion of a country depending on hydro-electric power.

What steps are being taken to ascertain how imminent are those climatological changes? What research is in progress to give hydro-electric engineers at least a forewarning of possible prolonged drought periods, say five years ahead? There is surely great need for a new technique, or a new combination of techniques, which the meteorologist and the hydro-electric engineer could work out together. The very rapid increase, and what is more important the accelerated rate of increase, in power consumption means that within the lifetime even of middle-aged engineers at present working in the hydro-electric field, vast new projects, costing scores of millions of pounds, will be set in motion to harness yet more of the water power resources of the world. In Canada, India, the Latin American countries, and in parts of Africa, enormous potential resources have been surveyed and their practicability established. Would it not be a tragedy, therefore, if even one of these great schemes were proved to have a limited life through a predictable change in climate?

There are meteorologists who claim to have evolved methods of long-term forecasting of climatological changes, and geologists have increased their knowledge of the earth's surface, over the last few decades. The progress of physical science has placed in their hands instruments of a hitherto unheard of degree of accuracy, enabling them to pursue their various interests with greatly increased efficiency. If, with these new techniques, a commission, sponsored perhaps by an international body such as the United Nations, were to initiate an investigation into the future of water-power schemes in general, and of specific projects of major size now under consideration, entirely from the scientific point of view, it might be that the future of hydro-electricity could be viewed with a more comfortable degree of certainty. No scheme need then be embarked on which

***SINCE** the inception of "Water Power" two years ago there has been an ever-increasing desire on the part of the readers that the paper shall be published monthly. "Water Power" has attained a very wide readership of the highest calibre throughout the world, and the Proprietors are satisfied that there is every justification for the more frequent publication of the journal.*

As and from the January 1951 issue, therefore, "Water Power" will be published monthly.

was subject to the risk of diminishing water supplies in perhaps only a generation of time.

The possibility of artificial rainfall on a vast scale would come within the purview of such an inquiry and the harnessing of tidal power should also be considered. Is the sway of the tides also subject to change over the centuries? If so, in what direction? Are normal precipitation and the glacial reserves of energy in the high mountains subject to purely cyclic change, and if so, what are the durations of the cycles? Are the changes permanent in character? Is the rate of change constant or liable to acceleration or deceleration? These are some of the questions that a commission might be able to answer in time.

The Queen opens Loch Sloy Station

IT was most fitting that a Scottish-born Queen should set the seal of Royal approval on the Loch Sloy hydro-electric scheme — the largest in Great Britain and the first major station in the North of Scotland Hydro-Electric Board's extensive programme. In a ceremony held at the station on October 18, Her Majesty officially inaugurated the plant by pulling a lever which caused two of the four turbo-electric alternators to be set in motion.

The plant, which has been fully described in WATER POWER (pages 100 and 185) comprises four 45,000 h.p. Francis turbines, operating under a head of 910 feet. The total capacity is 130 MW.

The Queen, responding to an invitation by Mr. Thomas Johnston, P.C., the Board's chairman, to perform the opening ceremony, said: "Everyone will, I know, join with me in expressing the warmest admiration for those whose vision, tenacity and technical skill have been welded together in facing and conquering so formidable a task. Their reward will be to see new strength surging into the very arteries of Scotland's being."

With the Queen's personal standard flying, for the first time, over a power station, Her Majesty then undertook a thorough inspection of the plant. Among those presented during the tour were Mr. A. M. McTaggart, Director of Balfour Beatty and Company Ltd., who were responsible for the dam; Mr. E. M. Fitt, Director of Edmund Nuttall, Sons and Company (London) Ltd., who constructed the tunnel; Mr. Leggat, Director of Messrs. Hugh Leggat Limited, the builders of the power house; Mr. H. Cunningham, Chairman of Sir William Arrol and Company Ltd., the contractors responsible for the pipeline; and Mr. J. T. Moore, Chief Engineer of the English Electric Company, the main contractors for the turbines, alternators, and electrical plant.

In the speeches, tribute was paid to the work of Mr. James Williamson, who had been consulting engineer to the Loch Sloy project from its inception, and to Sir Edward MacColl, the Deputy Chairman of the Board and its Chief Executive Officer.

Asian Development

DELEGATES of the Commonwealth Consultative Committee, which held meetings in London, have agreed unanimously to seek the approval of their governments to establish a technical assistance bureau for economic development in south and south-east Asia. It is hoped early steps can be taken to bring the bureau fully into operation to aid in the 6-year programmes for development submitted by the Commonwealth countries of the area — Ceylon, India, Pakistan, Malaya, Singapore, North Borneo and Sarawak. The formulation of these programmes represents a great achievement which the Committee recognised, since the first proposals for a co-operative development were made at the Colombo Conference less than a year ago. In that time, and especially since the Sydney meetings in May, the Commonwealth countries have carried out practical surveys of pressing development needs, and prepared detailed plans which were laid before the committee. The keynote of these plans was that they projected the essential work to be undertaken in the next six years if these countries are to make a real attack on their economic, political and social problems. Close liaison is to be maintained with the United Nations agency working in the area, and the International Bank for Reconstruction and Development will be kept fully informed of the position.

Proposed Engineering Centre for London

AS there have been rumours on this matter, the Engineering Centre of Glasgow have thought it advisable to make a clear statement of the position. Early this year the Glasgow Centre was asked by the British Engineers' Association to consider the formation of an Engineering Centre in London that would be capable of providing office accommodation, meeting halls, committee rooms and other facilities that are necessary for the good working of the Association's normal business. About 20,000 sq. ft.

of display space is envisaged for permanent exhibits, and every possible facility for visiting engineers.

The scheme aims at providing for Engineering Trade Associations, firms and visitors, a focal point in the heart of the Empire, operated on similar lines to the centre at Glasgow, primary consideration being given to the export markets of the world.

The matter now lies in the finding of a suitable building and the drawing up of a financial plan. Several buildings are now under scrutiny, and details will be sent out to the trade in due course. The whole prospect will, however, hinge on a close study of the possibilities of inflation and the effects of the re-armament programme on the engineering industry.

Tests for Transport

THE extensive constructional work incidental to almost every hydro-electric scheme makes the heaviest demands upon the efficiency of transport in getting great quantities of material to sites that a few years ago would have been regarded as virtually inaccessible. This modern trend, well foreseen by the manufacturers of British heavy-duty motor vehicles, was evident in the display of tractors, tippers, and excavating vehicles at the International Commercial Motor Show at Earls Court, London, in September. Some of the models shown were acclaimed by experts as being the complete answer to problems confronting surveyors and engineers responsible for civil engineering and similar works in all parts of the world. A notable example was the new "Big Bedford," the Vauxhall company's latest vehicle to come from its factories at Luton, Bedfordshire, England. For four years this model has been undergoing tests on the company's rough track, where 1,000 miles may be regarded as being the equivalent of at least five times that distance on ordinary roads. There have also been separate and special tests in tropical climates under the supervision of the firm's engineers, with the double aim of keeping quality and performance up and operational costs down.

Australia's Expansion

A SURVEY of industrial Australia published by the Union Bank of Australia, shows that in most of the states electrical power resources are strained to their limit by the rapid growth of industry. In the bold plans to meet this situation twenty-nine new stations hydro and steam powered are being built and thirty-six others have been suggested. If all these plans are carried through the total generating capacity will be increased threefold during the next two decades. Both coal and electricity resources are now strained to the uttermost, but with the developments foreshadowed under federal and state schemes it is estimated that there will be ample power for future expansion. In electrical equipment, the report says, it is only the heaviest types that remain in short supply, such as large motors and switchgear. Most other kinds of equipment are now produced in the country.

Central Africa's Future

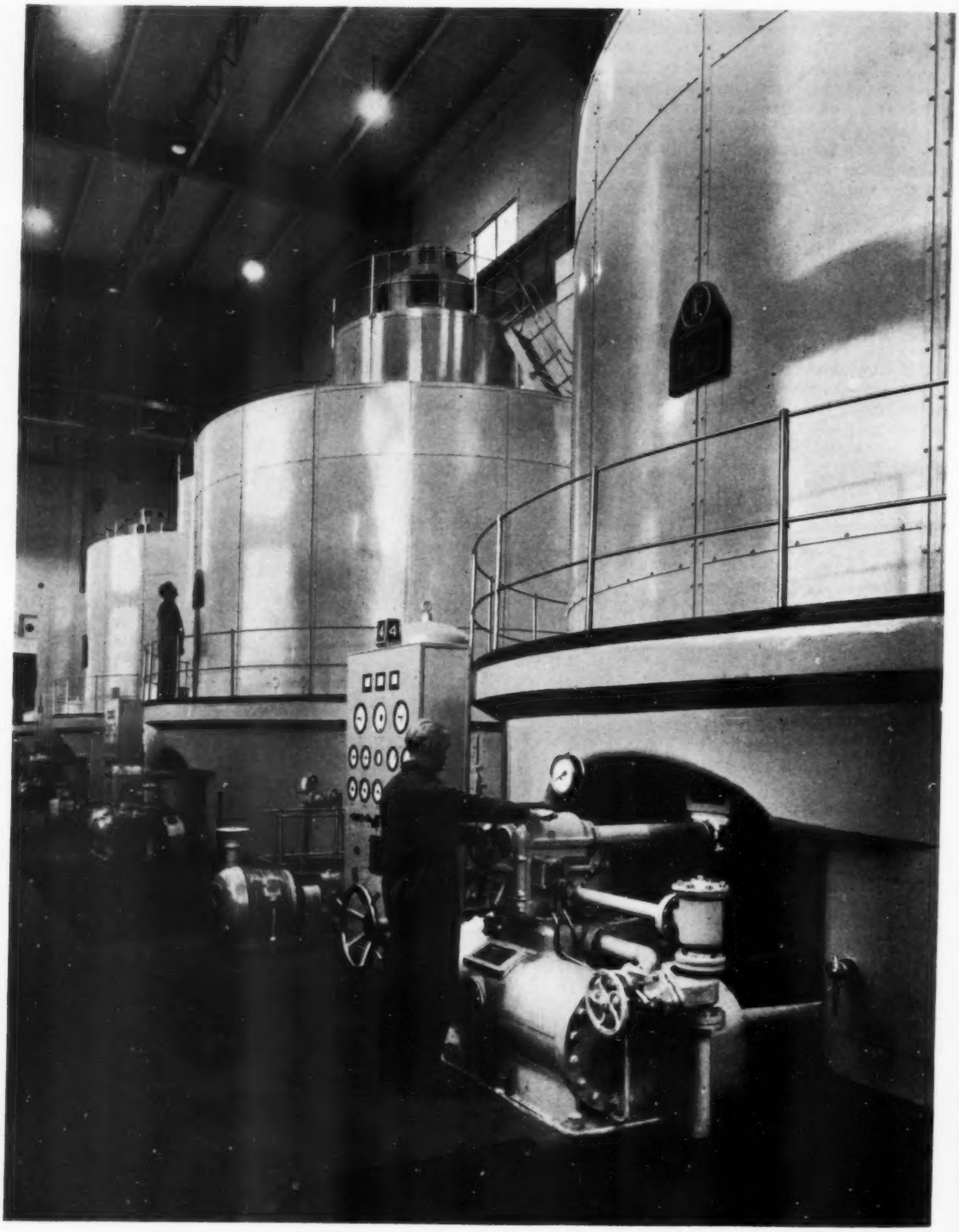
POTENTIALITIES of the Rhodesias' hydro-electric projects were the subject of pointed comment by Mr. Roy Welensky, leader of the unofficial members in the Northern Rhodesia Legislative Council, addressing the Bulawayo National Affairs Association. He was discussing the prospect of political union between the three territories—the two Rhodesias and Nyasaland —and expressed the hope of a further conference in London shortly. He urged the necessity of a strong British dominion of European stock in Central Africa, and suggested that the present European population of rather under 200,000 and the combined income in the region of £30 million was "enough to start on." He lamented the fact that the British Government had wasted £30 million trying to grow groundnuts in Tanganyika instead of spending the money on hydro-electric and other schemes that would have been more productive. He believed the initial difficulties attendant upon federal government would soon be overcome, and neither territory need fear either supercession or neglect, because any government pursuing such a policy would soon fall.

New Zealand's Needs

WITH the expansion of hydro-electric power almost to its maximum in New Zealand's North Island it is believed that geothermal generation may solve the present power shortage. Tests are being made by officers of the Department of Scientific and Industrial Research of New Zealand by means of test bores in a valley in the Wairakei district of North Island as part of the Government's new long range geothermal project. The expectation—for at present it can be placed no higher than that—is that geothermal steam may be employed, but Mr. W. Goosman, the Minister of Works, has warned the public against raising undue hopes; "but the results to date are very encouraging," he added. It will be some months before the tests have been fully analysed. Many departments are concerned in the experiments, but all are operating under the State Hydro Department. In the test bores, steam has been found at pressures of up to 90 lb. per sq. in. at depths between 600 ft. and 900 ft.

Volga Schemes

THE extensive changes in Russia's inland water transport as a result of the decision to construct the Kuibyshev and Stalingrad hydro-electric stations and other developments — dealt with elsewhere in this issue — are analysed by Pantelei Cherevko, deputy Minister of Inland Water Transport of the U.S.S.R. The new projects, he writes in an article in "Pravda," will involve great changes on the Volga as a navigable waterway, and the great reservoirs created by the constructional work on the new stations will enable much more powerful river craft to navigate the river than can be accommodated at present. In order to lengthen the period of navigability on the Volga and on the reservoirs, which are usually icebound longer than other waterways, cargo-carrying vessels of the icebreaker type, and even special icebreakers will be required. The anticipated deep draught of new vessels will also require the installation of automatic and electric lighthouses along the banks, as well as new shelters for river craft.



The Sloy Station as it appeared when formally opened by the Queen last month

Underground Power Stations

Dott. Ing. LUIGI GALLIOLI, Chairman of Studio Tecnico Ingegnere Gallioli, Milan, and a director of Hanson Clyde, Nissim & Partners Limited, London, discusses some of the factors which have to be considered in schemes of this type.

Des raisons d'ordre militaire suffiraient à justifier la construction de stations génératrices souterraines: l'alimentation des villes et, en particulier, des centres industriels en courant de force peut être un facteur décisif de l'aptitude d'un pays à résister à une agression soudaine et à faire la guerre avec quelque chance de succés. Mais l'argument esthétique entre aussi en ligne de compte; la construction souterraine permet enfin de résoudre le plus facilement les difficultés de site, et la simple nécessité économique est ainsi dans certains cas le facteur primordial. L'article çi-dessous traite de quelques aspects des projets de ce type.

La selección de una construcción subterránea para una central generadora de energía eléctrica puede ser influenciada por consideraciones militares, puesto que los suministros de fuerza motriz a todos los centros, y de manera especial los de naturaleza industrial, pueden ser un factor decisivo para que una nación pueda resistir una agresión repentina y pueda luchar en guerra con posibilidades de éxito. Pero es también necesario considerar los aspectos estéticos del caso; y existe la posibilidad de que tengan que considerarse dificultades del terreno que podrían ser más fácilmente solucionadas construyendo de manera subterránea, con el resultado de que bajo ciertas circunstancias el factor decisivo pueden ser necesidades de orden económico.

THE reasons for selecting an underground type of construction for an electricity power station may be of a purely military nature, but aesthetical grounds also come into the picture; there might also be site difficulties which could most easily be solved that way, so that in certain circumstances sheer economic necessity is the deciding factor. Nevertheless, military considerations generally predominate. The needs of modern warfare have influenced underground developments, but the advent of the atomic bomb and possibly worse, has made the widespread use of this type of construction a matter of major importance and urgency. Continuity of power supplies to all and particularly industrial centres can be a decisive factor in a nation's ability to resist sudden aggression and to wage war with any possibility of success.

Distribution lines and transformer stations are vulnerable to attack from the air, but any damage is not irreparable and supply interruptions can be guarded against by advance organisation and duplication of stocks and parts. Again, interconnections between generating centres have a flexibility that must minimise the consequences of damage to the distribution network.

No such safeguards can be taken to counteract the destruction of (or serious damage to) generating stations. Even casual damage may be irreparable on account of the distance from industrial centres, the nature of the hydraulic prime movers and electrical plant, and the merging of the plant and building structure into a working entity.

During the 1939-45 war power stations were successfully camouflaged, but this entailed systematic maintenance and successive adaptation according to the seasonable variations in the surroundings. Stretches of water are difficult to conceal, however, and can be seen from great distances, revealing dams and regulating devices. For these reasons a number of power stations, both storage reservoirs and generating plant, have now been constructed underground.

Fig. 1: Powerhouse showing alternators during erection

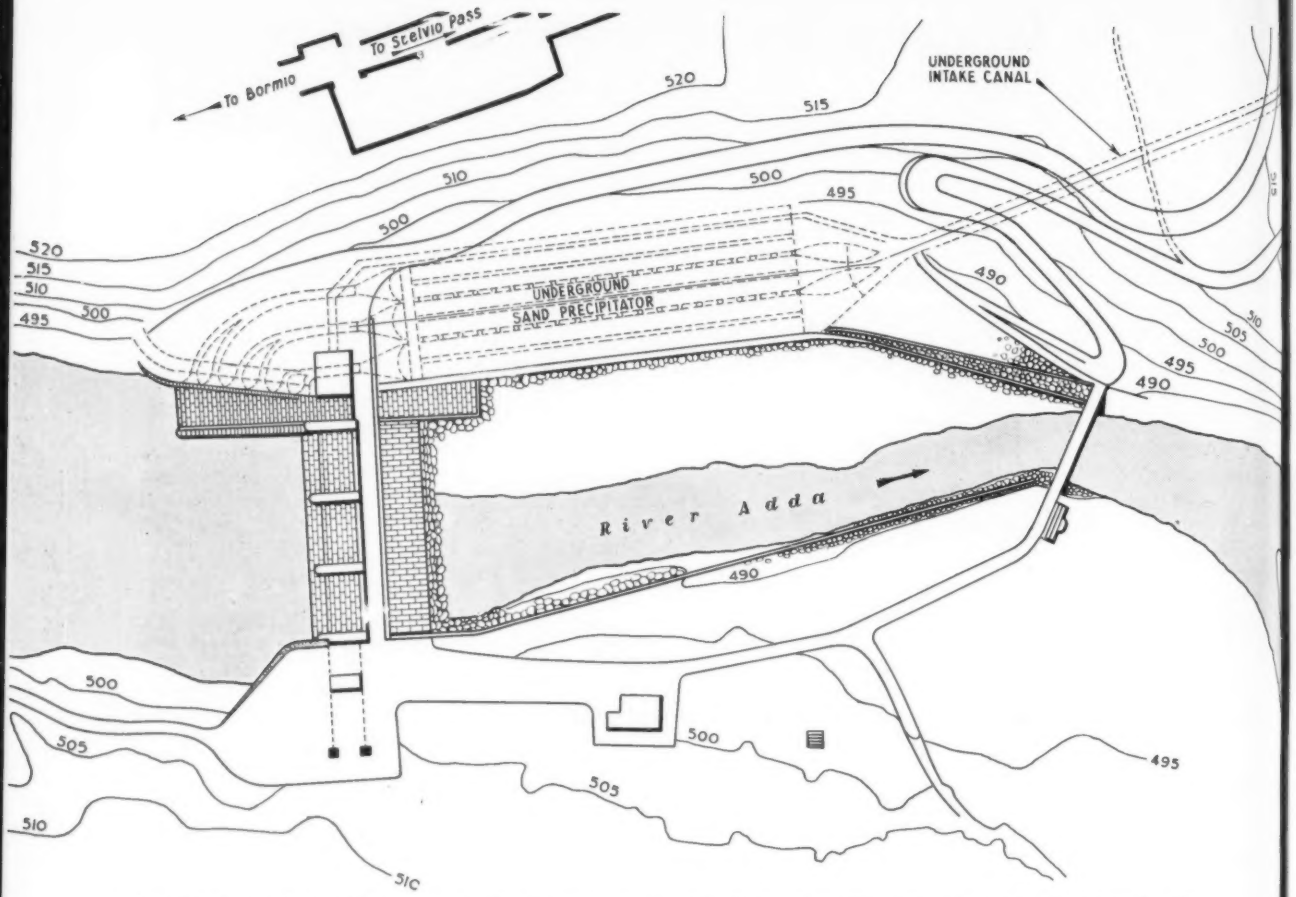
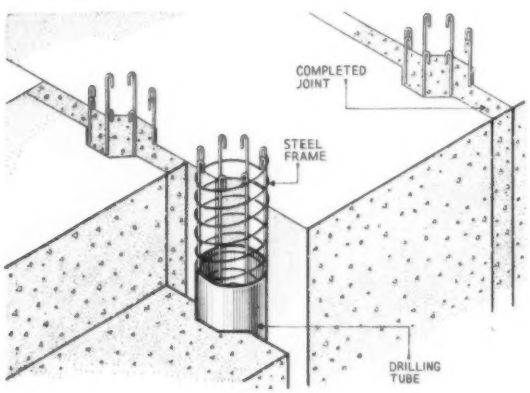
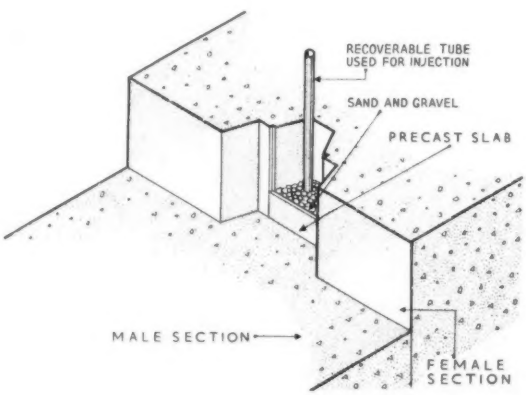


Fig. 2 (above): Layout drawing showing dam, underground sand precipitation system and underground intake canal

Fig. 3 (below): Showing two designs of interlocking caissons





There are, in addition to the foregoing, further good reasons for underground construction, such, for example, as the reduction of long and large pressure pipes, replacing part of the horizontal sections with more economical canals resulting in a substantial reduction of head loss, and, in certain cases, avoiding the expense of consolidating soil to bear the weight of the installation.

Living and working conditions, and the danger of flooding have been cited as possible disadvantages with underground plants, but experience has shown that good ventilation and secure construction can be assured. The S.T.I.G., Milan, has been privileged to design and supervise the erection of several hydro-electric installations with underground power stations. During the design stage and the actual erection of

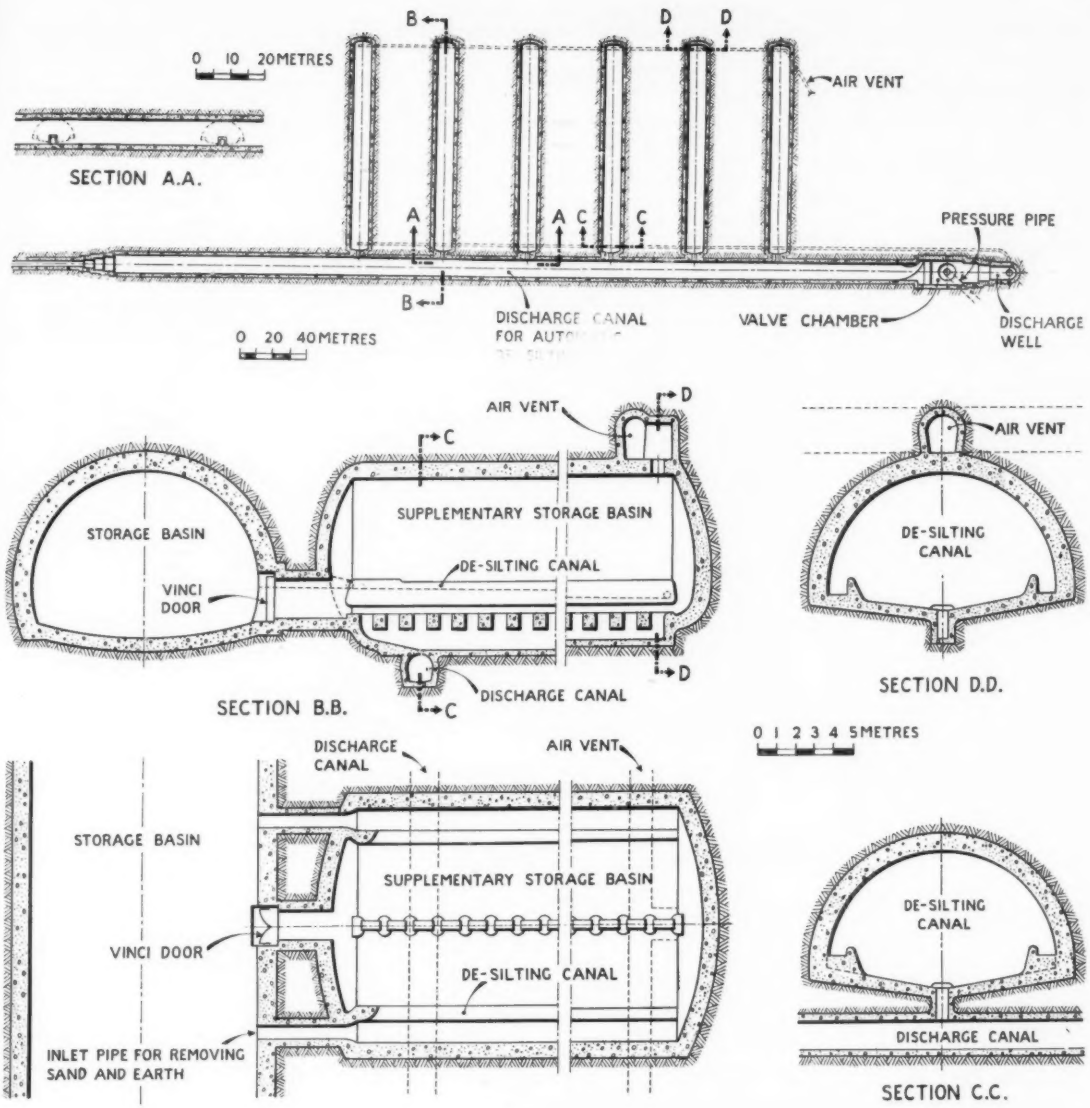
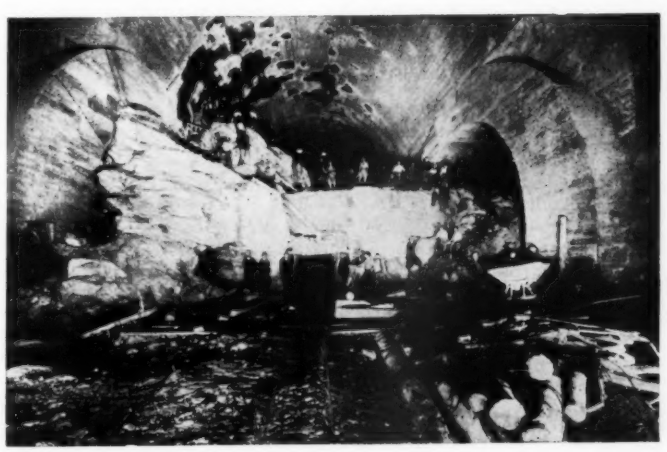


Fig. 4 (top of page): Transverse tunnels forming storage reservoir

Fig. 5 (above): Supplementary storage chamber showing de-silting arrangements

Fig. 6 (right): View of power house during construction showing rock core in process of removal



these plants many new problems had to be solved and it is felt that the difficulties encountered, the experience gained and the methods adopted, will be of interest to other engineers engaged on water-power projects.

The use of the term Underground Power Plant is not comprehensive enough inasmuch as so many other sections of the installation have necessarily to

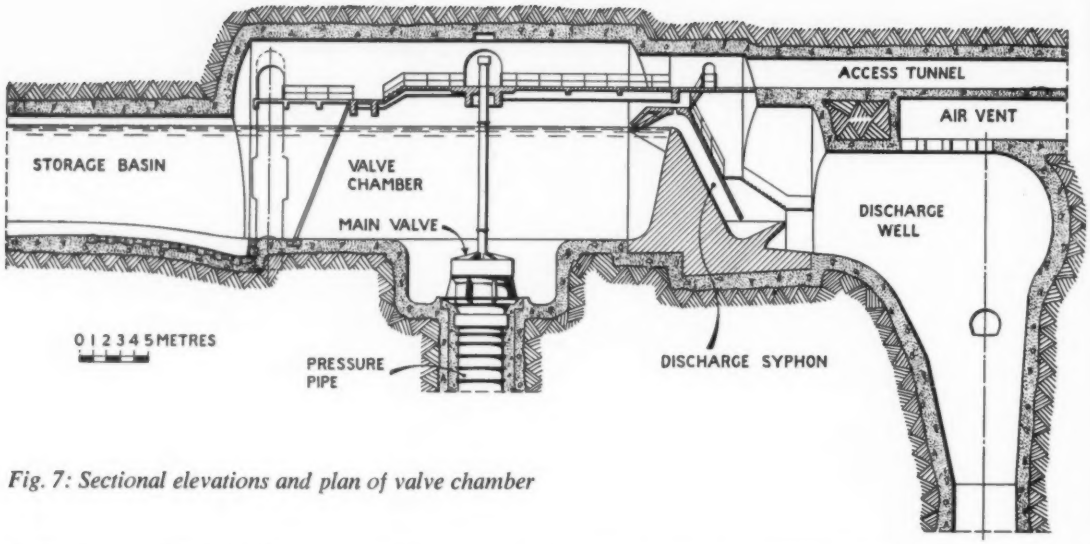
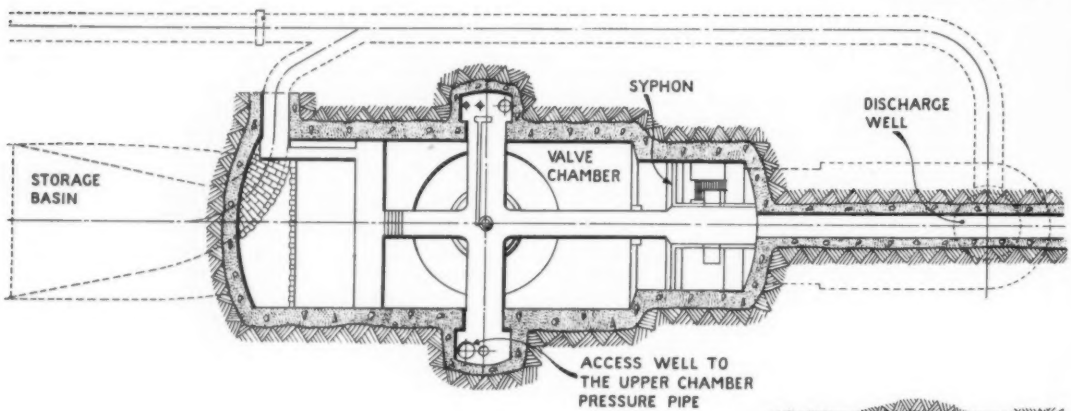
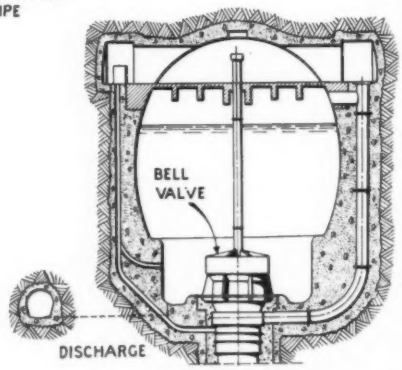


Fig. 7: Sectional elevations and plan of valve chamber





be constructed in the rock. The following case is typical and gives a practical instance of what is frequently involved.

Stazzona Project

The characteristics of this installation, which was designed for the Municipality of Milan, are of great interest. Its possibilities were first investigated in 1935, and the station was put into operation in December, 1938, a model of the plant being sent to the New York International Exhibition as a prototype of Italian underground power plants.

Main characteristics:

Max. water delivery	35 cu. metres/second.
Head	91.15 metres.
Power installed	45,000 h.p.
Storage basin	80,000 cu. metres.
Pressure pipes and station	Underground.
Hydraulic turbines	2 sets of 25,000 kW each (vertical shafts).
Transformers (in tunnel)	Ratio 10,000/150,000.

The water for the Stazzona station comes from the River Adda. The power generated is supplied to the City of Milan and is used mainly for the basic demand. As it was desirable to vary the output and increase it up to a predetermined limit, a compensating basin was erected upstream of the dam, having a capacity of approximately one million cubic metres.

Additional flexibility to meet immediate increases in demand was provided by a system of underground reservoirs, adjacent to the pipe line intake chamber, having a total capacity of 80,000 cubic metres. These two systems of reservoirs make it possible to alter the characteristics of the natural water supply, at least in regard to its hourly or weekly output. The other existing installations were thus unburdened and free to undertake the peak demands.

The flow of the Adda River, as with all Alpine rivers and streams, is very variable. Peak flow is reached in the spring when the thaws set in; it decreases in the summer and still further in the autumn. In the winter, particularly under conditions of intense frost, the flow is very slight. These conditions affect the operation of all stations in Northern Italy.

With the extensive interconnection of the distributing systems in Italy it was possible to dispose advantageously the surplus spring and summer power, thus compensating for the purchase of dearer winter

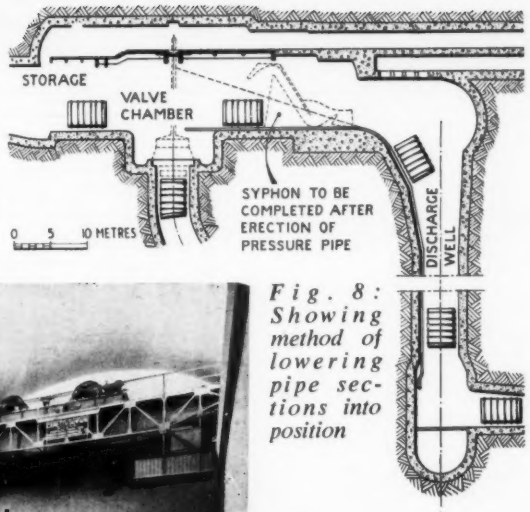


Fig. 8: Showing method of lowering pipe sections into position

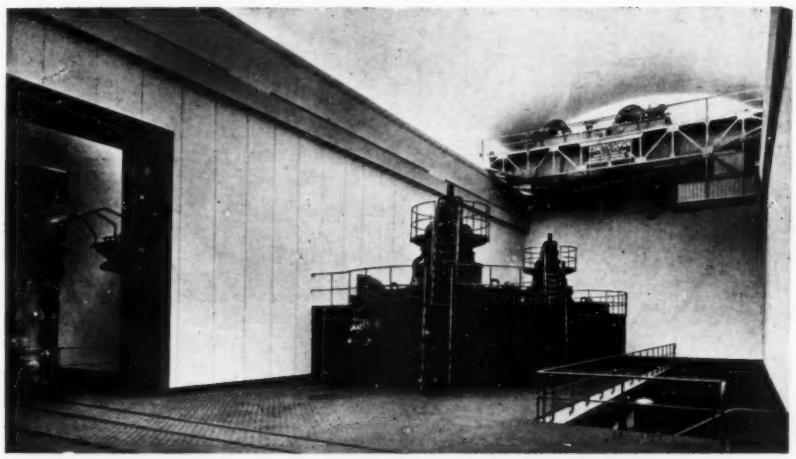
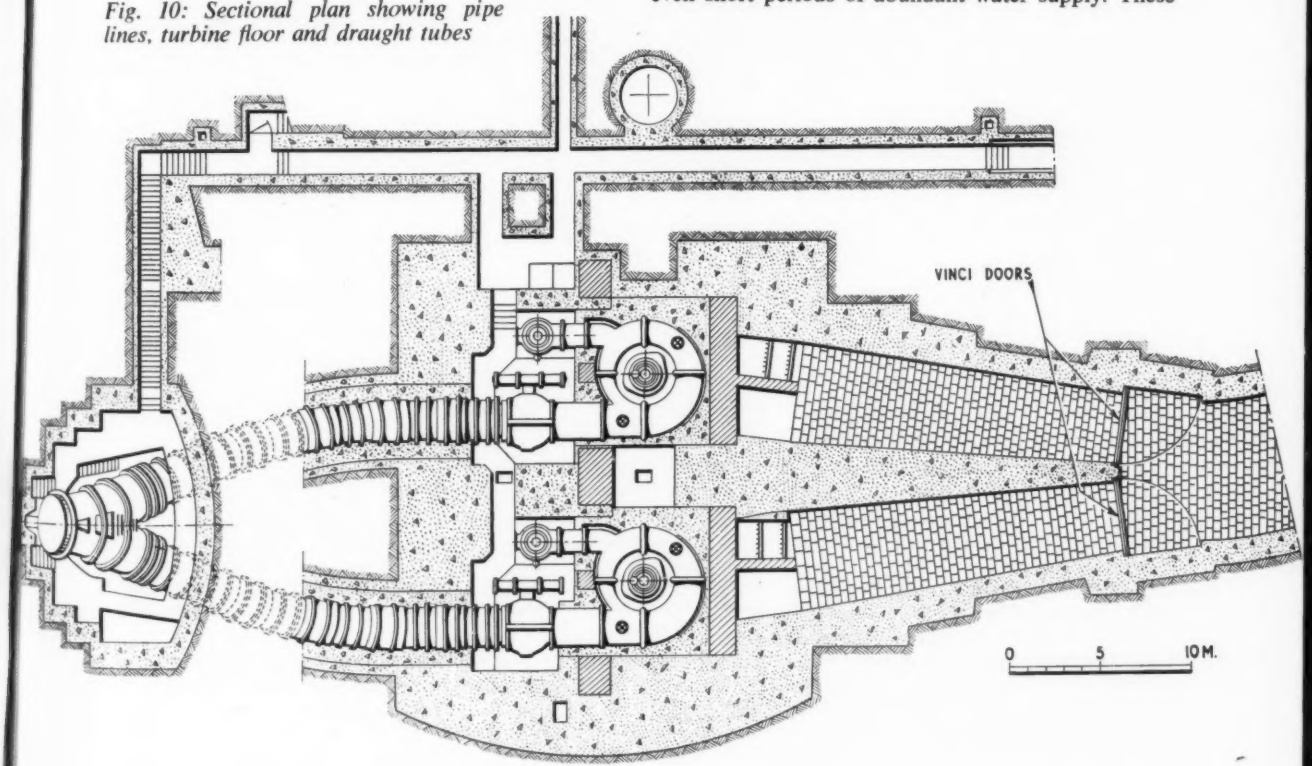


Fig. 9 (above): View showing alternators and overhead travelling crane

electricity from the southern part of the country. The abundance of power available in the spring throughout Italy as compared with the winter months results in substantial variations in price, in some cases in the ratio of as much as 1 : 5.

For this reason the Stazzona plant was designed to give a wide flexibility to permit a full exploitation of even short periods of abundant water supply. These

Fig. 10: Sectional plan showing pipe lines, turbine floor and draught tubes



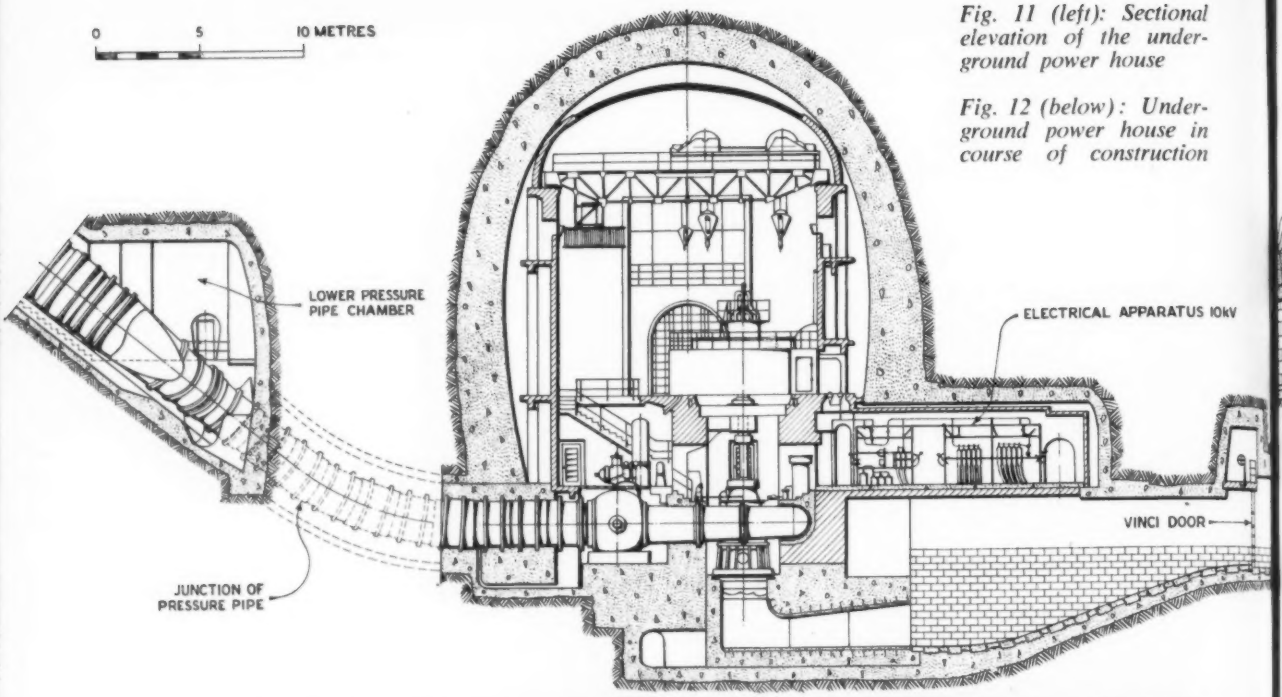


Fig. 11 (left): Sectional elevation of the underground power house

Fig. 12 (below): Underground power house in course of construction

design features, because of their success, were incorporated in the plans for stations at Lovere and S. Antonio, which will be described in a further article.

The Adda dam was erected at the foot of a gentle incline of the river bed so as to develop the optimum storage capacity. Trial excavations and bore holes supplied sufficient evidence of the nature of rock which had to be dealt with in the bed of the river. In the section surveyed the river flows over loose material brought down by a great landslide covering the original bed some 25 metres below. The old bed is formed of permeable alluvial material allowing substantial water leakage. It was therefore necessary to excavate and secure the dam foundations at a still lower level in an impermeable stratum.

The dam is of three 15-metre spans. Two sections are closed by two 6·50 metre sluices as shown in Fig. 2, and the third, which has a slightly raised sill, is closed by a single sluice. A fourth aperture, five metres wide, is provided for the gravel door channel. All the sluices are controlled by oil-pressure servo-motors. The illustrations show the main constructional features.

Foundations for the piling operations and for the shoulders and front dam walls were excavated by means of pneumatic caissons constructed in reinforced concrete. Adjacent caissons were interlocked by means of perforated concrete columns of the Simplex type, reinforced with vertical rods and a helical winding as shown in Fig. 3 (left). The trapezoidal recesses were filled with layers of concrete, built up successively, Fig. 3 (right), or layers of aggregate were used and subsequently injected with cement from the bottom upwards as shown in Fig. 3 (left). This construction was carried out without difficulty and resulted in a very substantial saving

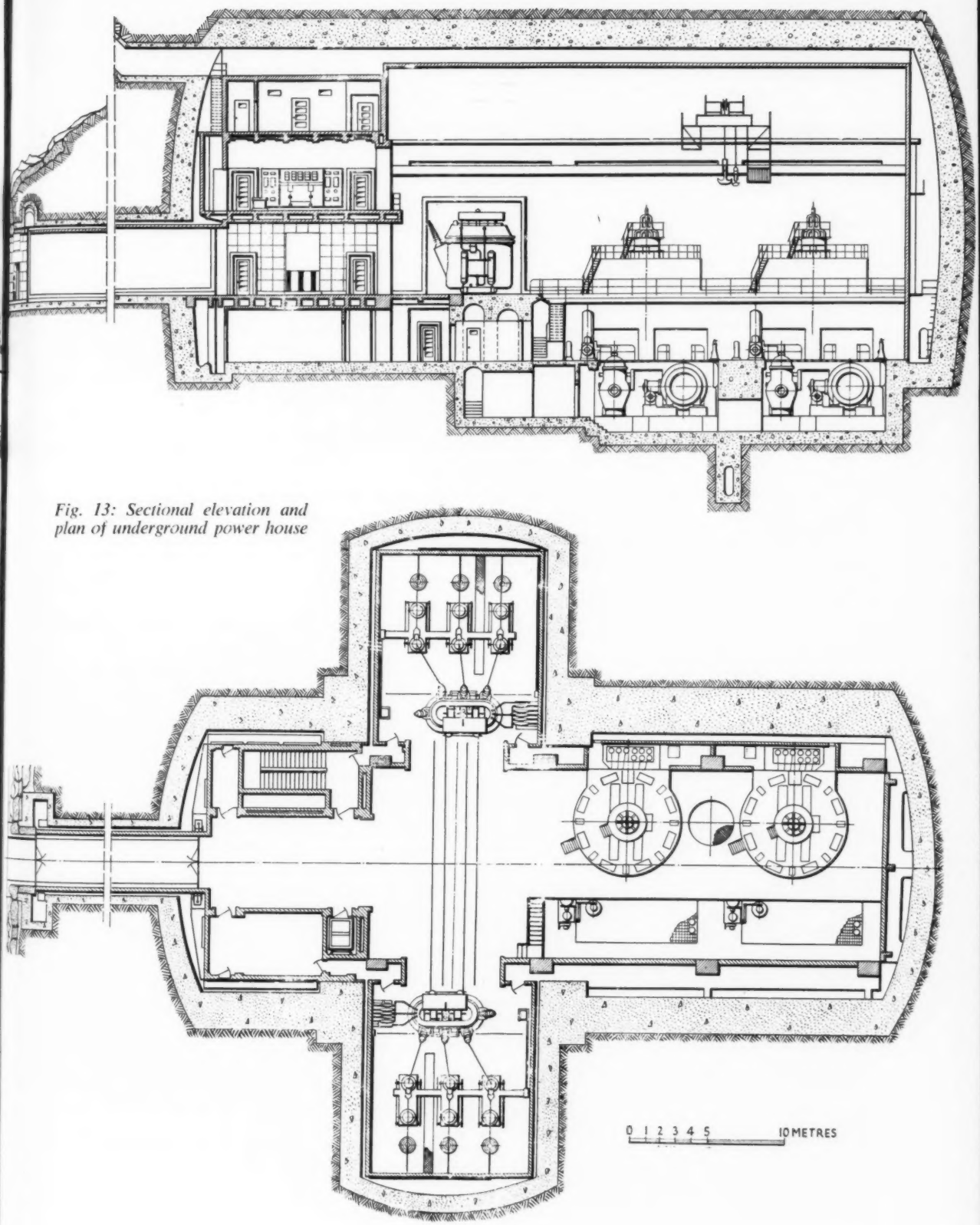


Fig. 13: Sectional elevation and plan of underground power house

compared with the normal system using diving bells.

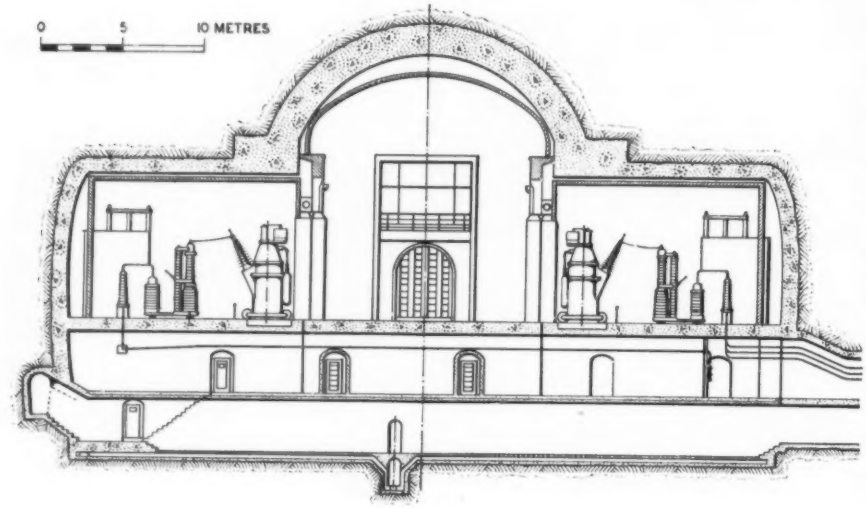
The footbridge and the road bridge over the dam are arranged as separate units, one for each span, with special supports to allow for the thermal expansion of each unit and to ensure a continuous four-point suspension for the bridge beam. Each unit is supported at one end by two sliding supports of steel plates, the smooth contact surfaces of each support being separated by a layer of graphite scales. The opposite end of the bridge rests on precompressed protected cork slabs. Due to possible variations in the deformation of the dam piles on which the bridge section rests, there is an unavoidable tendency to transfer the loading to three points, and the yield of the cork shapes is designed to correct this tendency.

Immediately downstream of the three intakes, which are intended to work mostly submerged, there is a continuous sand precipitator of the Doufur type. This is covered by a layer of soil rather more than two metres thick to avoid the easy detection and location of the intake. The levels of the intakes have been so selected as to allow the withdrawal of water in the event of partial damage to the dam.

The main supply canal, eight kilometres in length, delivers 35 cu. metres a second. To improve supply conditions the last 500 metres were suitably widened to 12 metres and lowered so as to create the required storage capacity. In addition, six transverse blind tunnels (Fig. 4) were driven, thereby creating a storage reservoir of about 80,000 cubic metres. The development of this underground storage system involved considerable difficulty. The junction of the tunnels, which are 12 metres wide, with the main canal and the removal of the inevitable accumulation of mud presented major problems. The former was resolved by reducing the tunnel section for a limited length in the neighbourhood of the junction. This restriction had no practical bearing on the operation of the plant as it was known that the exchange of water between the blind tunnels and the main reservoirs would normally be very slight. The mud accumulations were removed by controlling the flow of the water, particularly at the bottom of the tunnel. This was effected firstly by arranging in the enlarged main canal a rapidly sloping bottom connected, before the intake chamber of the pipe, to an independent discharge canal.

When the discharge is open all the delivery of the main canal flows at high speed along the bottom of

Fig. 14: Sectional elevation of transformer room



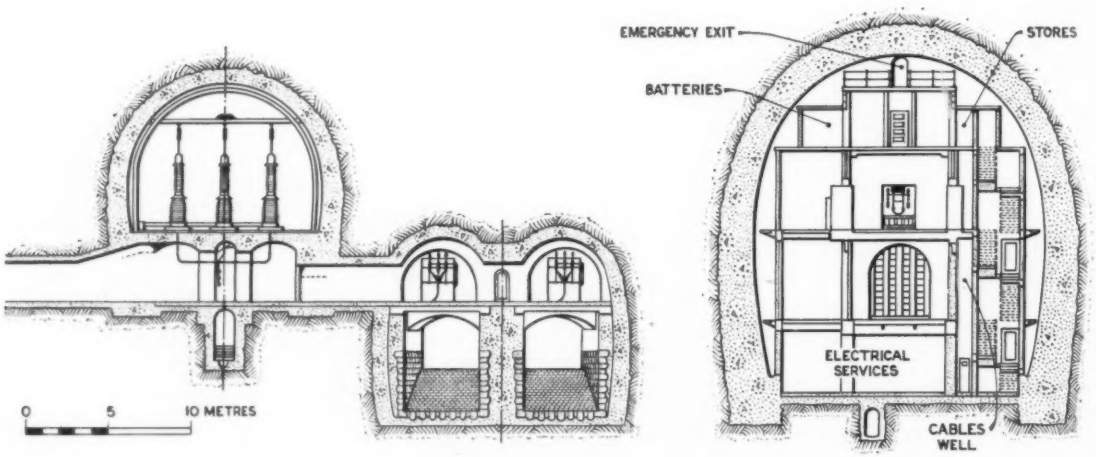


Fig. 15 (left): Transverse section of outgoing lines and (right) section through chamber containing electrical services

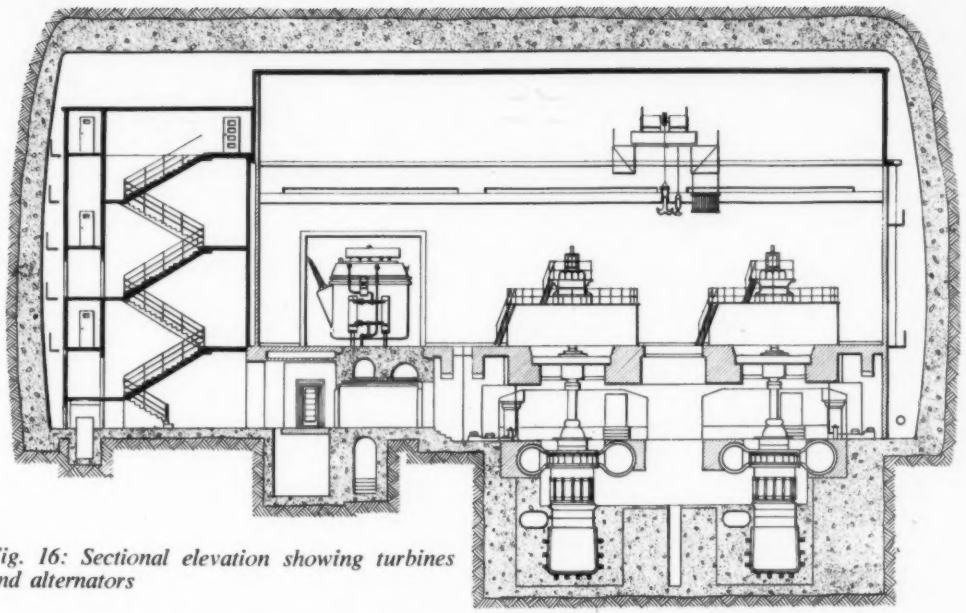


Fig. 16: Sectional elevation showing turbines and alternators

the enlarged section, stirring up the mud which is then held in suspension and carried away. Secondly, it should be mentioned that the floors of the blind reservoirs slope towards the centre, as shown in Fig. 5. At the foot of the reservoir tunnel two small overflow collecting canals were arranged and by closing a small door which controls the communication between the blind reservoirs and the main canal, combined with the assistance of two small-diameter tubes, the water of the main canal flows to the small overflow canals creating a modest but fast-flowing layer of water which agitates the deposits and carries off the mud in suspension. This water is led by canal to the main discharge of the syphons. In practice the results obtained with this scheme have been very satisfactory and it has been found possible to remove a mud layer of about 40 centimetres thick over an area of 15,000 sq. metres, i.e. about 6,000 cubic metres of mud.

The intake chamber of the pressure pipe is of ample dimensions and is connected by three self-levelling siphons to the large vertical discharge shaft (Fig. 7). The siphons discharge only the water exceeding the requirement of each working phase. At the bottom of the intake chamber and at the intake of the pressure pipe, a bell valve is fitted. A highly delicate control device provides for the rapid closing of the valve each time the speed of the water becomes excessive.

Another difficulty which had to be faced was the introduction and erection of the pressure pipe. This was lifted in sections through the discharge shaft and stored in the main reservoir. The siphons were constructed in the same way. The pipe sections were lowered and fitted in the tunnel. The successive stages of this work are illustrated in Fig. 8. At the foot the pipe is divided into two branches as shown in Fig. 10; the chamber in which these branches are located has a safety door which closes automatically in the event of the pipe breaking, thus preventing the flooding of the station.

Power Station

The power station (Figs. 1 and 11) was erected in a large central nave, 50 metres long, 31 metres high and 18 metres wide internally. Access is gained by a tunnel of 150 metres length, large enough to allow the transport of the bulkiest parts of machinery (Figs. 11 and 13). Before reaching the central nave, ample space has been provided for auxiliaries, service rooms, control rooms, batteries and personnel lodgings. On a level with this central nave two lateral tunnels for the accommodation of the transformers were excavated, and sufficient space is provided nearby for such auxiliary services as switchboards, etc. The engine room contains two Francis turbines with vertical shafts, each direct coupled to an electrical generator.

This station is erected inside an inner structure which is independent of the outer tunnel. The runways for the overhead travelling cranes are carried

Fig. 17: Pipeline, showing bifurcation

by reinforced concrete pillars and these, with all the remaining structures, are connected by means of a hinged joint to the main external nave. This joint allows for a slight relative movement between the two structures. Over the crane runways is a roof of hollow elements, formed of prefabricated units, which completely isolates the inside of the power station from the roof of the central main nave. To keep the space between these two main structures dry, part of the cooling air exhausted from the generators is passed through this space before being discharged into the open.

The main nave was constructed first by excavating the crown and building up the arched sections of reinforced concrete slabs. These sections rested on scaffolding at the central portion and on the rock at the abutments sections. Corresponding with the joints at the extremities of the crown slabs, shafts were sunk, in successive stages, to the floor level and subsequently filled in with concrete, thus forming pillars on which the crown was sustained when the main nave was excavated; finally the walls between the pillars were completed in concrete about 4 metres thick by underpinning.

To close the two ends of the nave, curved walls were used thus transmitting the thrust of the rock to the walls. The most delicate points in this construction were the connections to the main nave of the side chambers containing the transformers (Fig. 14). By means of suitably reinforced rings this difficulty was satisfactorily overcome.

After the completion of the underground work, cement injections at pre-determined points were carried out to ensure a reliable contact between the external concrete structure and the rock. Although the rock was not very good and in certain points infiltration of water took place, not even the slightest inconvenience occurred to the inner structure and anything like dampness was practically non-existent. The transformers and service rooms were also enclosed in compartments detached from their relative tunnels. Inside the whole power station a perfect atmosphere with a normal degree of moisture was obtained.

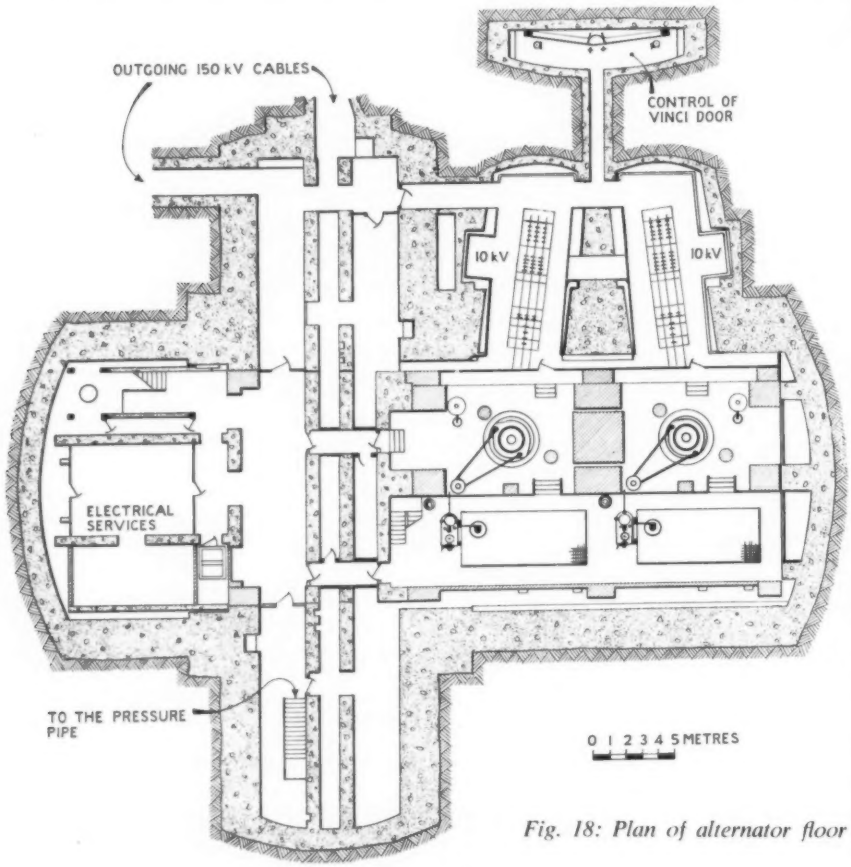


Fig. 18: Plan of alternator floor

To avoid the transmission of vibrations to the concrete structures of the tunnels, the machines were mounted on isolated bases independent of the main tunnel structures save, of course, at their foundations. The parts supporting the alternators called for particularly laborious study to prevent the transmission of dangerous vibrations. The shape and dimensions of the special sections adopted were such that it can be stated that the results achieved were highly satisfactory. These results were further enhanced by the type of insulation adopted, which was formed by layers of bituminous boards and cork granules. Even the slight vibrations of the plant supporting structures could not be detected in any other part of the station.

The water drained above the discharge pipe level was conveyed into the latter, downstream of the measuring weir. The water at lower level was conveyed into a well and from there raised to the discharge pipe. The power station is ventilated by a series of air ducts in which the air drawn from the exit tunnel is circulated. The air from the station is exhausted through a main duct running along the roof, and the ventilation is further improved by the heat developed by the machines and by the natural draught, supplemented by a suction device connected to the water discharge shaft.

The discharge from the turbines is effected by the usual cones which can be isolated by doors located before the junction with the discharge pipe. As the

Continued on page 246

Turbine Efficiency Formulae

By G. G. McDONALD, Professor at the University of Sydney, Australia.

In this article he proposes to modify the two "Moody" 1942 formulae to take account of the "design" of the turbine, including losses of the kinetic or "shock" type.

PROFESSOR L. F. MOODY'S 1942[1] step-up formula:—

$$(1-E)\,/\,(1-e) = (d/D)^{1/5} \quad - \quad - \quad (1)$$

connecting the hydraulic or internal efficiency ratio e and diameter d of a turbine model with the corresponding E and D of its full-size geometrically similar prototype fails to allow for internal losses of the kinetic or "shock" variety, which are proportional to the square of the flow velocity and a constant small fraction of the overall head. This formula can be expanded a little by being written in its general form in which the Reynolds' Numbers r and R of the model and prototype appear,

$$(1-E)\,/\,(1-e) = (r/R)^{1/5} \quad - \quad - \quad (1a)$$

Even in this expanded form, the formula is mathematically incapable of allowing for kinetic losses except through an empirical variation of the index 1/5 whose value is already fixed by considerations of simple boundary layer theory. The object of this short note is to set down, without proof, rational formulæ which will take shock losses into account. Fully developed "smooth turbulent" flow is assumed in both model and full size turbines. In small models, "laminar" or "transitional" flow may occur, but this may be changed to the smooth turbulent type by placing a "turbulence grid" before the model or by other means.

The efficiency of the prototype can be shown to be,

$$E = 1 - a - (b/R^i) \quad - \quad - \quad - \quad (2)$$

and of the model,

$$e = 1 - a - (b/r^i) \quad - \quad - \quad - \quad (2a)$$

Geometrically similar "flow patterns" are assumed in model and prototype, that is, Q/ND^3 for prototype $= q/nd^3$ for model, where Q, q are the flow quantities and N, n the rotational speeds.

In these expressions, a is an experimental non-dimensional "shock" coefficient, and b an experimental non-dimensional "surface friction" coefficient; a and b together define the "design" of the turbine. Boundary layer theory on the simplest assumptions of Blasius and Prandtl indicates that the index i should be between 1/4 and 1/5; probably nearer 1/5 for smooth turbulent flow because fresh boundary layers are formed at the leading edges of guide and runner vanes, and pass through the passages without coalescing.

Equations (2) and (2a) can be re-arranged to give the required rational step-up formula,

$$(1-E)\,/\,(1-e) = [\,1+(c/R^{1/5})\,]\,/\,[\,1+(c/r^{1/5})\,] \quad - \quad (3)$$

where $c\ (=b/a)$ in an experimental non-dimensional coefficient characteristic of the particular design of turbine, including the effects of kinetic and surface friction losses. It will be seen that equation (3) reduces to equation (1a) when $a = o$; that is, when shock losses are neglected.

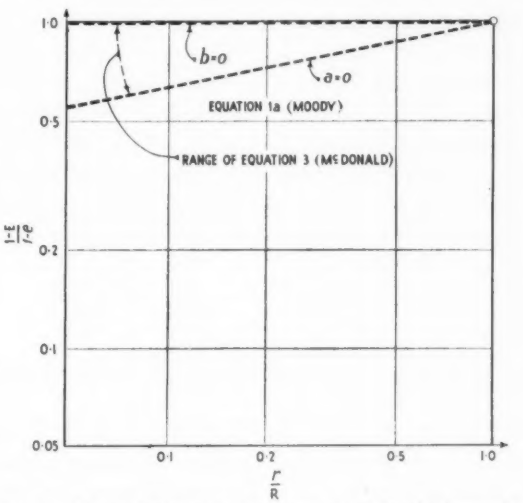


Fig. 1. The relationship between the Moody formula and that of the author

Fig. 1 shows the connection between the general form (1a) of the Moody formula and the step-up formula (3) proposed by the author. It will be noticed that (3) is wider in its "sweep" than (1a) and thus much more likely to fit experimental figures obtained from widely different designs of turbines.

Prandtl-Schlichting approximation

Professor Prandtl's close empirical approximation for the surface friction coefficient for the smooth turbulent régime is also of interest. It gives

$$E = 1 - a - [b/(\log R)^{2.58}] \quad - \quad - \quad (4)$$

and

$$e = 1 - a - [b/(\log r)^{2.58}] \quad - \quad - \quad (4a)$$

from which

$$\frac{(1-E)}{(1-e)} = \frac{1+[c/(\log R)^{2.58}]}{1+[c/(\log r)^{2.58}]} \quad - \quad (5)$$

The Prandtl-Schlichting coefficient $b/(\log R)^{2.58}$ is a closer approximation than the Blasius and Prandtl coefficient $b/R^{1/5}$ especially at the higher values of Reynolds' Number common in full size turbines.

If the flow in the model and full size turbines is of the fully developed "rough-turbulent" type, it can be shown, as a matter of interest, that,

$$E = 1 - a - [\,b/[\log f\,(D/k)]^2\,] \quad - \quad (6)$$

$$e = 1 - a - [\,b/[\log f\,(d/k)]^2\,] \quad - \quad (6a)$$

and

$$\frac{(1-E)}{(1-e)} = \frac{1+[\,c/[\log f\,(D/k)]^2\,]}{1+[\,c/[\log f\,(d/k)]^2\,]} \quad - \quad (7)$$

Continued on page 246

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An American Survey

By W. B. LANGBEIN, Hydraulic Engineer, U.S. Geological Survey, who discusses potentialities of Water Power development in the United States

Un flot continu de plus de 53 000 mètres cube par seconde — équivalent à une nappe d'eau de 400 000 hectares et de 30 cms de profondeur — coule chaque année dans plus de 1000 stations génératrices majeures aux Etats Unis, sous une hauteur de chute moyenne de 27 mètres. L'énergie totale produite est d'environ 78 millions de kilowatt-heures. En dépit de ce chiffre élevé la production hydraulique d'énergie électrique aux Etats Unis n'atteint encore que 20% des ressources potentielles. L'article çi-dessous étudie cet etat de choses.

A través de más de mil centrales hidroeléctricas de mayor importancia de los Estados Unidos de la América del Norte pasan 123.400 hectáreas/metros de agua por año, representando un flujo constante de 42.480 metros cúbicos por segundo, con un salto promedio de 27,10 metros. La energía combinada de esta vasta cantidad de agua y su salto produce un conjunto de 78.000 millones de kilovatios/hora de energía eléctrica. A pesar de esta elevada cifra representando la generación hidráulica, la producción de energía eléctrica por medios hidráulicos en los Estados Unidos tan sólo representa el 20% más o menos de las posibilidades del país. En este artículo se facilita un estudio de la situación.

ABOUT 1,000 million acre-feet of water, equivalent to a continuous flow of 1,500,000 cubic feet per second, flows annually through more than one thousand major hydro-electric power plants in the United States, under an average head of 89 feet. This combination of water and head produces an aggregate of about 78,000 million kilowatt-hours of electric energy. In spite of this high figure for water power generation, the production of electric energy by water in the United States is as yet only about 20 per cent. of that potentially possible. In the present economy the development of water power is balanced against the costs of supplying the demand from other energy sources such as coal, oil, gas, and wood. In some areas the trend has been away from water power, and in other regions water power has been reported economically justifiable only where part of the costs can be shared with other multiple-purpose benefits such as navigation, irrigation, and flood control. Nevertheless, the future of water power is secure, since it utilises a renewable resource and conserves our important non-renewable fuel reserves.

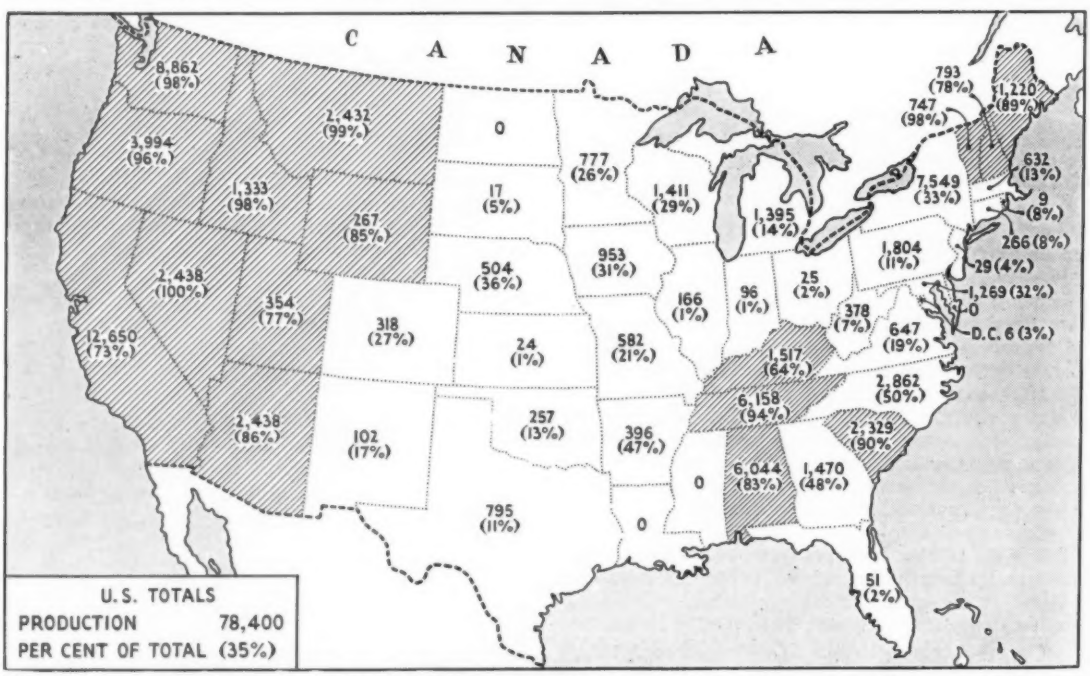


Fig. 1: Annual production by hydro-electric power stations in the U.S. (shown in millions of kWh); the percentage of hydro production to total production of electrical energy is bracketted

TABLE 1.—POTENTIAL POWER 50% OF TIME, WITH STORAGE—IN THOUSANDS OF HORSE-POWER

State	Drainage Basin												Total
	North Atlantic Slope	South Atlantic Slope	Ohio River Basin	St. Lawrence River Basin	Upper Mississippi R. Basin	Missouri River Basin	Lower Mississippi R. Basin	Rio Grande and Western Gulf	Colorado River	Great Basin	Pacific Slope—California	Columbia and Oregon Wash	
Ala.	—	575	705	—	—	—	—	—	—	—	—	—	1,280
Ariz.	—	—	—	—	—	—	—	—	3,545	—	—	—	3,545
Ark.	—	—	—	—	—	—	518	—	—	—	—	—	518
Calif.	—	—	—	—	—	—	—	—	65	190	5,751	—	6,006
Colo.	—	—	—	—	—	111	44	—	696	—	—	—	851
Conn.	125	—	—	—	—	—	—	—	—	—	—	—	125
Del.	5	—	—	—	—	—	—	—	—	—	—	—	5
Fla.	—	34	—	—	—	—	—	—	—	—	—	—	34
Ga.	—	729	—	—	—	—	—	—	—	—	—	—	729
Idaho	—	—	—	—	—	—	—	—	—	39	—	4,070	4,109
Ill.	—	—	0	0	497	—	—	—	—	—	—	—	497
Ind.	—	—	135	24	0	—	—	—	—	—	—	—	159
Iowa	—	—	—	—	232	—	—	—	—	—	—	—	232
Kans.	—	—	—	—	—	60	43	—	—	—	—	—	103
Ky.	—	—	543	—	—	—	—	—	—	—	—	—	543
La.	—	—	—	—	—	—	52	17	—	—	—	—	69
Me.	806	—	—	—	—	—	—	—	—	—	—	—	806
Md. & D.C.	286	—	—	—	—	—	—	—	—	—	—	—	286
Mass.	211	—	—	—	—	—	—	—	—	—	—	—	211
Mich.	—	—	—	400	—	—	—	—	—	—	—	—	400
Minn.	—	—	—	132	256	0	—	—	—	—	—	—	388
Miss.	—	96	14	—	—	—	43	—	—	—	—	—	153
Mo.	—	—	—	—	344	216	183	—	—	—	—	—	743
Mont.	—	—	—	—	—	1,096	—	—	—	—	—	1,153	2,249
Nebr.	—	—	—	—	—	219	—	—	—	—	—	—	219
Nev.	—	—	—	—	—	—	—	—	482	5	—	—	487
N.H.	417	—	—	—	—	—	—	—	—	—	—	—	417
N.J.	60	—	—	—	—	—	—	—	—	—	—	—	60
N. Mex.	—	—	—	—	—	—	3	92	41	—	—	—	136
N.Y.	627	—	—	4,205	—	—	—	—	—	—	—	—	4,832
N. Car.	—	622	196	—	—	—	—	—	—	—	—	—	818
N. Dak.	—	—	—	—	—	218	—	—	—	—	—	—	218
Ohio	—	—	77	0	—	—	—	—	—	—	—	—	77
Okla.	—	—	—	—	—	—	334	—	—	—	—	—	334
Oreg.	—	—	—	—	—	—	—	—	—	0	132	6,180	6,312
Pa.	638	—	330	30	—	—	—	—	—	—	—	—	998
R.I.	13	—	—	—	—	—	—	—	—	—	—	—	13
S. Car.	—	752	—	—	—	—	—	—	—	—	—	—	752
S. Dak.	—	—	—	—	—	598	—	—	—	—	—	—	598
Tenn.	—	—	1,800	—	—	—	—	—	—	—	—	—	1,800
Tex.	—	—	—	—	—	—	71	224	—	—	—	—	295
Utah	—	—	—	—	—	—	—	—	1,430	200	—	—	1,630
Vt.	87	—	—	107	—	—	—	—	—	—	—	—	194
Va.	208	227	214	—	—	—	—	—	—	—	—	—	649
Wash.	—	—	—	—	—	—	—	—	—	—	—	12,146	12,146
W. Va.	55	—	730	—	—	—	—	—	—	—	—	—	785
Wisc.	—	—	—	157	350	—	—	—	—	—	—	—	507
Wyo.	—	—	—	—	—	379	—	—	52	2	—	97	530
H.P.	3,538	3,035	4,744	5,055	1,679	2,897	1,291	333	6,311	436	5,883	23,646	58,848
KW	2,639	2,264	3,539	3,771	1,253	2,161	963	248	4,708	325	4,389	17,640	43,900
KW per sq. mile	18	8.2	17.3	29.2	5.7	4.1	2.9	0.8	17.8	1.6	37.6	67	14.5

Quantitatively, the use of water for electric energy production in the United States exceeds any other use of water, but with the important difference that water power is primarily non-consumptive. Reference to Fig. 1 will show that about 35 per cent. of all the electrical energy used in the United States is now generated by water power. Where the conditions are suitable, as in the Rocky Mountain and Pacific Coast states, stream flow generated about 85 per cent. of the electric energy sold in 1946. The remainder was generated by burning coal or oil.

Fig. 1 shows by states and for the country, the 1946 production of hydro-electric energy generated by public utilities in millions of kilowatt hours, and the percentage of hydro production to total production of electric energy. Hydro accounts for more than 50 per cent. of the total electric energy produced in the West, northern New England, and in Tennessee, Kentucky, Alabama, and South Carolina.

The total installed capacity of water-power plants of the world in 1945 was reported as 58 million kilowatts and of this total the United States accounted for about 17 million kilowatts or nearly one-third.

This study assembles figures on potential and installed capacity and on the power generated as a measure of the extent to which water-power resources are being utilised. The figures used are those for 1946. Calculations are made to show the variations in the distribution of water-power resources among the major basins of the country and the quantity of water used to produce power. Data on potential power are those made available by the U.S. Geological Survey.

TABLE 2.— WATER POWER STUDY

Drainage Basin (1)	Potential power (1,000 kW hrs.) (2)	1946 Generation (1,000 kW hrs.) (3)	Ratio of production to potential (per cent.) (4)	Average equivalent head (ft.) (5)	Total water use—80% Eff. (c.f.s.) (6)	(1,000 acre-feet) (7)	Mean annual flow* (c.f.s.) (8)
North Atlantic	23,120,000	7,881,377	34	54.1	246,100	177,800	210,000
South Atlantic Slope and Eastern Gulf	19,830,000	7,171,143	36	68.2	177,800	128,400	325,000
Ohio River	31,000,000	14,348,343	46	73.0	332,300	240,000	255,000
St. Lawrence River	33,030,000	8,519,430	37	66.4	216,800	156,700	140,000
Upper Mississippi River Basin and Hudson Bay	10,970,000	2,634,627	24	33.2	134,200	96,900	96,000
Missouri River	18,940,000	2,975,650	16	96.2	52,200	37,700	70,000
Lower Mississippi River Basin	8,440,000	1,007,601	12	99.9	17,100	12,300	205,000†
Rio Grande and Western Gulf of Mexico	2,180,000	653,125	30	75.9	14,500	10,500	55,000
Colorado River	41,240,000	5,886,689	14	240	41,600	30,000	23,000
Great Basin	2,850,000	1,314,979	47	287	7,780	5,620	17,000
Pacific Slope Basin in California	38,450,000	11,176,695	29	519	36,300	26,300	80,000
Columbia River and Pacific Slope Basin in Oregon and Washington	154,520,000	14,798,039	10	116	215,500	155,700	345,000
Total	384,570,000	78,367,698	20	89.2	1,492,180	1,077,920	1,821,000

*Average for period 1921-45.

†Includes flow originating in lower basin only, total outflow of Mississippi River at mouth is 620,000 c.f.s.

Data on current capacities, heads, and production were furnished by the Federal Power Commission. Where possible the results are presented for each major drainage basin, but otherwise by states.

The approximate present installed turbine capacity for public use in each major drainage basin is shown on Fig. 2. The figures shown on this chart are derived by increasing the reported generator capacity by 10 per cent., a general average for the excess of turbine over generator power. The turbine capacity (for public use) installed up to 1946 amounted to about 16.1 million kilowatts. To this should be added about 1 million kilowatts of industrial or non-utility water power, that is, power developed for direct use by industry on the site and not for public sale. Recent trends indicate a reduction of the importance of such non-utility power development.

The Federal Power Commission* estimates that plants with capacity aggregating about 77,000,000 kilowatts remain to be developed, making the ultimate potential about 93,000,000 kilowatts.

The total installed turbine capacity in 1921 was about 6,000,000 kilowatts, about 6.5 per cent. of the ultimate. The installed turbine capacity reached 18 per cent. by 1946. As a rough approximation, the statement might be ventured that if economic conditions justify, resources yet available should permit a comparable rate of increase in capacity for the next 25 years, before the rate can be expected to slacken.

As a result of the multiple-purpose concept of water development, the trend in hydro-electric power for the past few years has been towards development by the Federal Government. The possibilities for cost distribution and the flexibility of use afforded by multi-purpose projects, makes it almost certain that this trend will continue. Present Federal capacity totals about 4,900,000 kilowatts, nearly 30 per cent. of the total, public and private as follows:*

Capacity of existing Federal plants (kilowatts)

Built by	Existing
Bureau of Reclamation	2,500,000
Corps of Engineers	644,000
Tennessee Valley Authority	1,777,000
Indian Irrigation Service	10,000
National Park Service	3,000
	4,934,000

The existing installed capacity will be increased by 2,440,000 kilowatts at plants now under construction by the following Federal agencies:

	Initial Capacity (kilowatts)
Bureau of Reclamation	757,000
Corps of Engineers	1,602,000
Tennessee Valley Authority	81,000
	2,440,000

Presently authorised plants and ultimate additional installations at existing plants or at plants now under construction will total over 12,000,000 kilowatts. When this capacity has been installed, the total Federal hydro-electric plant will aggregate about 17,000,000 kilowatts, an amount equal to the present hydro capacity, public and private.

The overall picture of Federal water power is as follows:

Existing plants	4,934,000 kilowatts
Additional facilities planned at existing plants	2,417,000
Plants under construction (initial capacity)	2,440,000
Additional facilities planned at plants under construction	1,791,000
Plants authorised but not ready for contract	5,319,000
	16,901,000

*Address by F. L. Weaver, Federal Power Commission, Jan. 18, 1949.

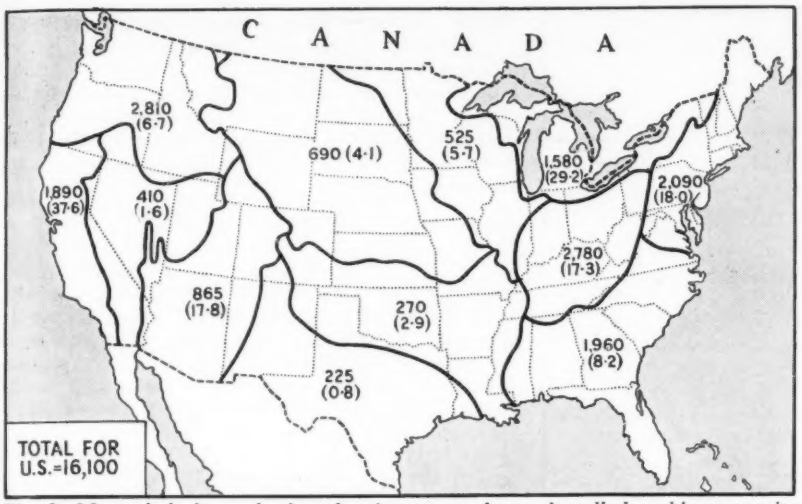


Fig. 2: Map of drainage basins showing approximate installed turbine capacity in thousands of kilowatts and, in brackets, potential power in kilowatts per sq. mile

Federal construction and installation will bring total capacity in the United States to about 29 million kilowatts, about 31 per cent. of the ultimate as estimated by the Federal Power Commission.

Potential hydro-electric energy

There is a physical limit to the amount of energy that a stream can generate. It depends on the fall that can be developed, on the amount of water available for use, and on the efficiency of generation. Estimates of this quantity expressed in terms of kilowatts will be called " potential power " and in terms of kilowatt-hours " potential energy."

Table 1 summarises the potential water power by major drainage basins and by states. The estimate of potential water power is based on the assumption that all power and reservoir sites which have been surveyed and considered feasible from an engineering standpoint are utilised and that the electric power is developed with an overall efficiency of 70 per cent. The availability of water for power depends on the annual and seasonal variation in stream flow. The table shows the potential resource computed on the basis of the water available 50 per cent. of the time with all reservoir sites developed. This total comes to about 44 million kilowatts (59 million horse power).

The area density of the potential power is shown on Fig. 3, in terms of kilowatts per square mile. The country-wide average is 14.5 kilowatts per square mile. The highest density is shown in the Pacific-Northwest where it averages 67 kilowatts per square mile, and the lowest in the Rio Grande and western Gulf drainages where the density is only 0.8 kilowatt per square mile.

The figures of potential power resources in terms of kilowatts reported in Table 1 and shown in Fig. 3 are in effect measures of the ultimate energy that it is practical to generate in each basin. To make this clear and to distinguish these figures from those of installed power or estimates of potential power in terms of potential capacity reported in the previous section, it is desirable to express these figures of potential power in terms of potential annual production of energy in kilowatt hours. This information is given in Table 2, which also summarises by drainage basins, the production figures and heads of individual plants for 1946. Column 2 lists the potential power in kilowatt hours, computed on the basis of complete and continuous use of the power resources, by multiplying the potential power figures listed in Table 1 by 8,760, the number of hours in a year. Column 3 lists total hydro-electric generation in 1946 in 1,000 kW-hrs. Column 4 lists the percentage of the power resources utilised.

The largest blocks of undeveloped power are to be found in the Columbia, Colorado, Missouri, and St. Lawrence River Basins, where multi-million kilowatt hydro-electric plants (excluding tidal power) are already projected by several governmental agencies. The next 25 years will doubtless see considerable

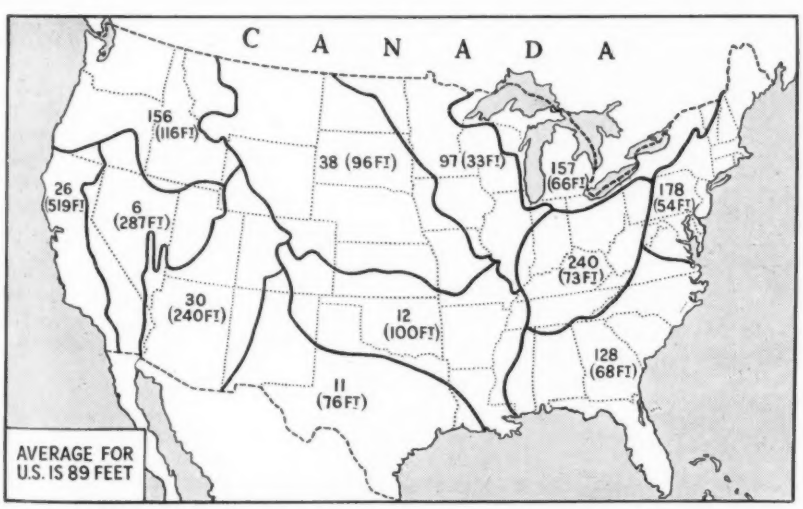


Fig. 3: Map of drainage basins showing water used by hydro-electric plants, in millions of acre ft. per sq. mile and, in brackets, the average equivalent heads, in feet

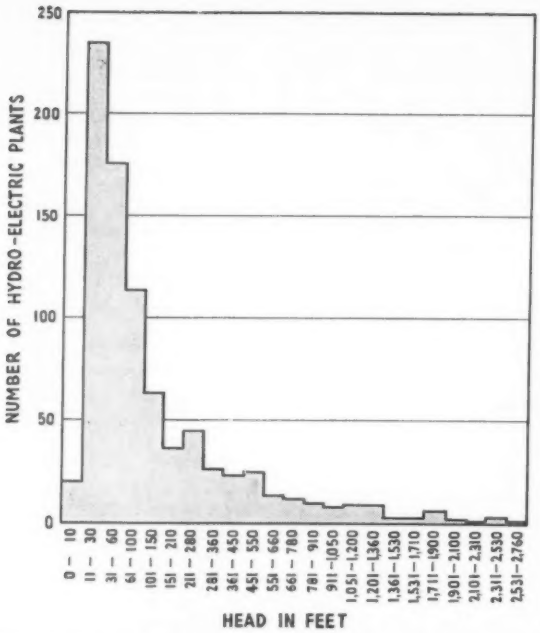


Fig. 4: Graph showing plants in relation to operating heads

further utilisation of water-power resources throughout the country.

The potential energy reported in Table 2 can be developed only by installations with capacity in excess of the median flow. Plants on rivers with comparatively little storage, like Conowingo on the Susquehanna River, Bartletts Ferry on the Chattahoochee River, may have installed capacities several times the potential power at median flow.

Capacity is also installed for peaking purposes on streams with pondage or storage. The ratio of the installed capacity to the potential power would depend on a number of circumstances. The capacity might depend on whether the storage carryover is daily, weekly, or seasonal. The actual ratio depends on intended methods of use and the relation of a plant to others in the same or a related system. This comparison of the Federal Power Commission estimate of ultimate installed capacity with the above estimate of potential power based on the 50 per cent. regulated flow indicates a general average of over two. The reciprocal of this ratio corresponds roughly to the "plant factor," as reported by the Federal Power Commission. The plant factor is defined as the ratio of the actual output in kilowatt hours over a year, against the output that could be produced by the installed capacity operating continuously. The plant factor, therefore, measures the utilisation of the capacity in producing energy. Before the war, plant factors at hydro-electric plants averaged about 50 per cent.; since 1942, it has averaged about 60 per cent.

Quantity of water used and developed heads

The amount of electricity generated per year by falling water is equal to:

$$\text{Total 1,000 kW hr.} = \frac{QHE}{1.35}$$

Where Q is mean flow of water through turbines in cubic feet per second, H is the average head in feet, and E is the efficiency.

A study of the efficiency of most modern hydro-electric plants shows that it averages about 80 per cent. On this basis, the amount of water that flows through the turbines can be approximated by the following formula:

$$Q = 1.69 \times \frac{1{,}000 \text{ kWh}}{H}$$

The ratio kW-hr./H was computed for each plant, and the ratios were totalled for each basin. The sum when multiplied by the factor 1.69 gives estimate of the water used for power generation. These estimates are listed in Column 6 of Table 2. Corresponding figures in acre-feet are shown in Column 7 and in Fig. 2. The largest quantities of water are used in the East, particularly in the Ohio River Basin; because of the successive use of water on the Tennessee river, one of the principal tributaries of the Ohio River. The amount of water used reflects two factors, (1) the amount of water available, and (2) the intensity of the use of water for power generation.

The flow of most rivers in the United States is gauged by the Geological Survey. Estimates of the total water flow in the rivers of each major basin based on records of the Geological Survey are listed in Column 8 of Table 2. These figures indicate the total water available for use in the respective basins, and may, therefore, appropriately be compared with the amount of water actually run through the turbines.

It was noted that the head available for hydro-electric plants shows marked regional characteristics. Operating heads for plants in the eastern states are commonly less than 100 ft., whereas the opposite is true in the West. To show this, the average head of the hydro-electric plants in each basin was computed, and results listed in column 5 of Table 2, and on Fig. 3. In making these calculations each plant was weighted according to the amount of water that it used. The results are equivalent to saying, for example, that all the hydro-electric power generated in the North Atlantic coast basins was produced at an average head of 54 ft. The average for the United States is 89 ft. The head of hydro-electric plants in California averages over 500 ft.

Heads of individual plants were classified as shown graphically on Fig. 4. Since heads are required to be reported to the Federal Power Commission only for plants with capacities greater than 2,500 kilowatts, the figures and distribution apply to such. The maximum head reported is 2,558 ft., for the 40,000 kilowatt Bucks Creek plant of the Pacific Gas & Electric Co. on North Fork Feather River in California.

This article was prepared under the direction of C. G. Paulsen, Chief Hydraulic Engineer, and his acknowledgements are also due to B. E. Jones, Chief of the Power Branch, U.S. Geological Survey, for data on potential power.

Rip Bits Limited. It has been pointed out to us that "rip bits," referred to in our article on the Sloy power station (page 192, September-October issue), is in no sense a generic term for detachable drilling bits but is a registered trade mark owned by Rip Bits Limited to designate the products they manufacture.

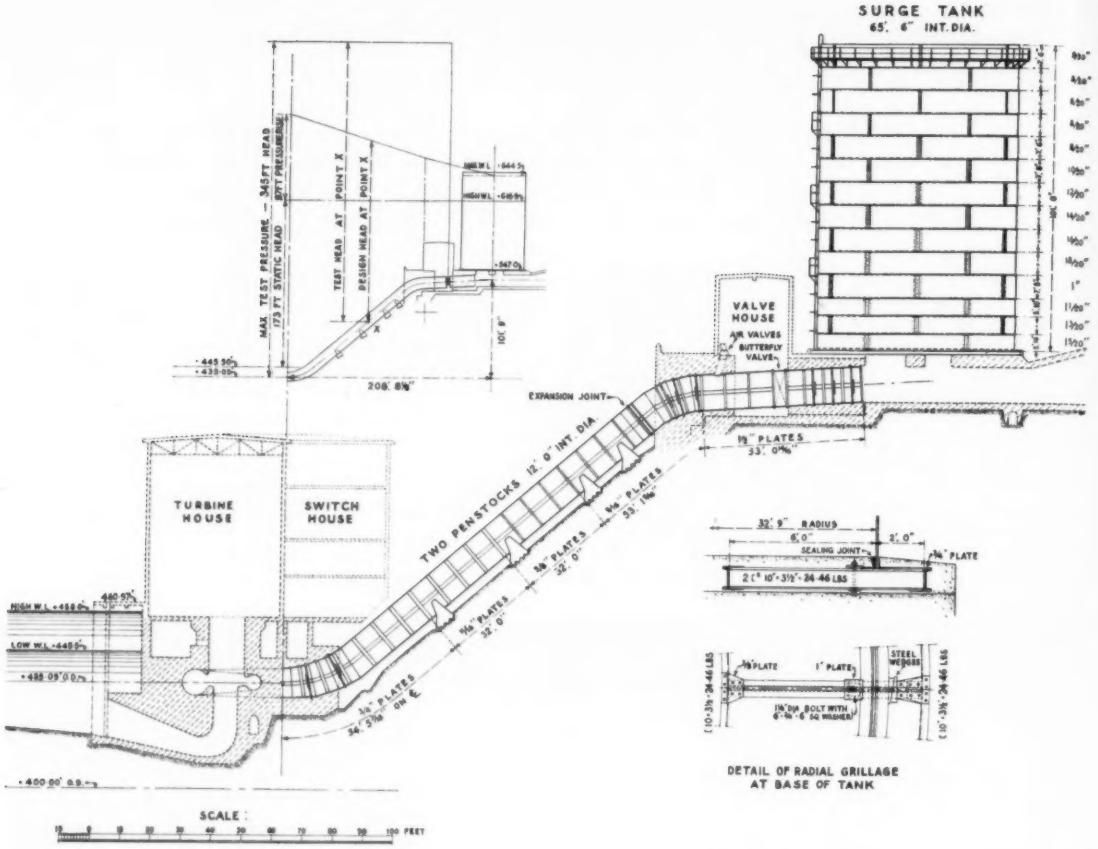
The Pollaphuca Station

The River Liffey not only supplies one of the main ingredients of a famous Irish stout, but also furnishes the City of Dublin with water supply and electric power; in this article particulars are given of penstocks and surge tank associated with the power development.

IN its circuitous course from the mountains south-west of Dublin to the sea the Liffey has been developed for production of power by the Electricity Supply Board of Ireland in a series of three steps. The Pollaphuca station is the uppermost and most important of these three steps, and work on this section was started before the war, but the first set was not put into operation until 1944, after wartime difficulties in the supply of essential equipment had been overcome. The second set was commissioned sometime later and the completed development has been generating about 30 million kilowatt hours per annum since 1947, principally for peak load use.

A large impounding reservoir situated near the head waters of the River Liffey supplies water to the plant and also furnishes water supply for the city of Dublin. Water for the power station is supplied through a 16 ft. diameter pressure tunnel about a quarter of a mile long to a steel surge tank, 65 ft. 6 in. diameter and 101 ft. high, supported on a reinforced concrete base. From the base of the surge tank two steel penstocks each 12 ft. diameter and about 200 ft. long supply the two turbines. Each set consists of a Kaplan turbine capable of developing 25,400 h.p. when driving a generator nominally rated at 15,000 kW, but able to

Aerial view of the Pollaphuca station with its prominent surge tank



take overload. The nett design head of the turbine is 154 ft. and the maximum static head can rise to 173 feet. The sets are housed in a conventional open-air power station equipped with loading bay, workshops, control and switch rooms, offices, etc. Access to the loading bay for heavy loads is provided by a steeply inclined cable-operated railway.

The accompanying aerial photographs illustrate the layout at the power station and show the penstocks and surge tank, which form important adjuncts of the plant. The main contractors for the plant were the English Electric Co., Ltd., England, and their sub-contractor for the penstocks, surge tank and incline railway were Sir William Arrol & Co. Ltd., of Glasgow, Scotland.

Constructional details of the station's penstocks and surge tank

Penstocks

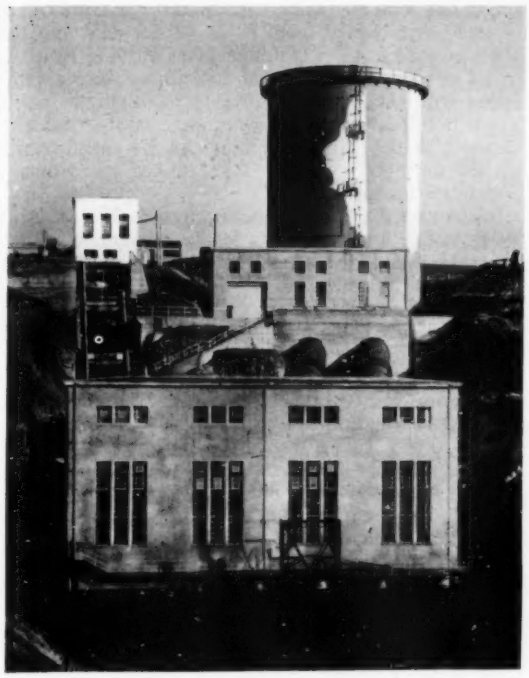
Each penstock is 12 ft. diameter and is constructed of riveted steel platework. At the upper end immediately below the surge tank, a valve house contains two Glenfield & Kennedy 12 ft. diameter butterfly valves which are hydraulically operated and fitted with automatic trip gear and air valves. Below the valve house the pipes run steeply down to the power house and the bends at the top and bottom of the slope are rigidly secured by massive concrete anchor blocks. Immediately below the upper anchor block, expansion joints are fitted on the pipes and between the top anchor block and the power station each penstock is supported on four intermediate concrete supports which are fitted with sliding bearings.

The effect of water hammer arising from the rapid shutdown of a set and causing increased pressure in the penstock had to be considered in the design. In the event of a sudden drop in load due to an electrical fault or lightning the turbines close rapidly in order to keep the speed variations within reasonable limits. The increase of pressure produced thereby was guaranteed not to exceed 25 per cent above the maximum static head. In actual practice the pressure rise thus produced did not exceed 20 per cent under the worst conditions. The heads adopted for the design of the Pollaphuca penstocks were as follows:—

Bottom of penstock—Maximum static head 173 ft. + 50 per cent = 260 ft.

Top of penstock—Head from maximum surge in tank above centre-line of pipe at top = 110 ft.

After completion, the penstocks were subjected to a site pressure test and the head adopted for this test amounted to 345 ft. head at the bottom end of the pipe line, or twice the maximum static head. The heads adopted for design and test purposes are shown on the accompanying diagram which also indicates the appropriate head for any intermediate portion of the pipe line. It can be seen from this diagram that the effect of the test pressure is more severe on the



Two aspects of the power station buildings

upper ends of the penstocks and although some excess metal was available above the expansion joints, due to the adoption of a minimum plate thickness of $\frac{1}{2}$ in., the general effect of the test pressure was to increase the stresses by an amount varying from about 33 to 50 per cent above the design figures. The maximum stress adopted for design was 6 tons per sq. in. and accordingly, under test, the penstocks were stressed to a maximum of about 9 tons per sq. in. The plate thicknesses varied in steps of $\frac{1}{16}$ in. from $\frac{3}{4}$ in. at the bottom to $\frac{1}{2}$ in. at the top.

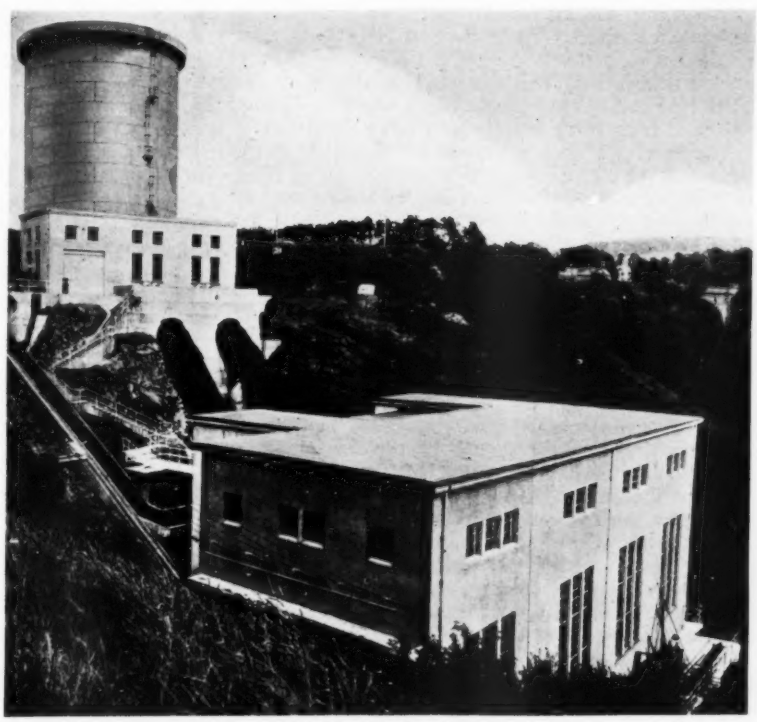
Plates 8 ft. wide were rolled, two to the round, and riveted on site on either side of the horizontal seams. Triple-riveted butt joints with internal and external cover straps were used on the lower portions of the penstocks and double-riveted butt joints on the upper ends. Rivets varied from 1 in. diameter at the lower ends to $\frac{3}{4}$ in. at the upper ends, joint efficiencies being of the order of 84 per cent for the triple-riveted and 75 per cent for the double-riveted joints, relative to the full strength of the plate.

The circumferential joints, situated at 8 ft. centres, between successive rings of pipe were formed by external cover straps riveted to the pipe rings by double rows of rivets on each side of the joint for the bottom ends of the penstocks and single rows of rivets for the upper portions. As no internal cover straps were used, the rivets in these joints act in single shear only and accordingly give very much lower efficiencies —of the order of half those obtained on the longitudinal joints. This reduction in strength at the circumferential joints was quite acceptable as the longitudinal forces are relatively minor, being confined to bending forces, and forces due to friction at sliding bearings set up by temperature movements of the penstocks.

The bends in the penstocks were formed by mitreing short lengths of pipe. The mitred joints were welded in the shop, successive portions of half pipe being joined together to form suitable lengths for transport. At site, the top and bottom halves of the bend portions were joined together by the standard longitudinal riveted joints and then successive portions of the bend were jointed by riveted external circumferential cover straps. These site circumferential joints were arranged on parallel portions of the pipe, clear of the mitres, to avoid awkward shaping of the covers.

The expansion joints fitted at the upper ends of the penstocks are of the stuffing box type and were made of heavier metal than adjacent portions of the penstocks in order to preserve the necessary stiffness during manufacture. Intermediate supports were fitted with curved steel saddles which contact the pipes over an arc subtended by 150° and at the points of support the lower halves of the pipes are fitted with curved wearing plates. Means of greasing the sliding surfaces have been included.

After satisfactory completion of the site pressure



test the penstocks were painted inside and outside with bituminous compound.

Surge Tank

The surge tank at Pollaphuca is of the cylindrical restricted orifice type and the diameter of the tank was settled by considerations regarding stable governing of the turbines and the severe combination of low head and large pressure tunnel led to the adoption of a diameter of 65 ft. 6 in. When the diameter was settled the necessary height of the tank was determined after calculation of the water rise and fall under the most severe operating condition of sudden rejection or throwing on of full load. Rejection of full load due to a sudden failure of a transmission line or other fault developing, and involving the shutting off of both turbines in three seconds, determines the maximum rise of water in the tank. The conditions at Pollaphuca led to the adoption of a height of 101 ft. above the concrete base.

This combination of height and diameter produced very severe design conditions and the tank approaches the limit of what can satisfactorily and economically be done with ordinary riveted structural steelwork. Fortunately, the loads on the tank caused by the water pressure are quite determinate and no allowance beyond the maximum water head in the tank requires to be made. In view of this a higher working stress than that used for the design of the penstocks was considered permissible and a maximum figure of 7.6 tons per sq. in. was adopted.

As in the case of the penstocks, the tank was constructed of riveted steel platework and practically all the riveting was done at site. The tank was built of plates formed into 14 horizontal rings and a general plate width of 8 ft. was adopted, with the exception of the three lowest rings where a narrower width was used to limit the maximum weight of plate and to facilitate transport. The horizontal rings were constructed of six plates to the round and these were butt-jointed with internal and external riveted covers. The horizontal joints were single line riveted lap joints, the plate rings being made alternately in and out.

The necessary plate thickness for each ring of the tank was calculated from the maximum water pressure on the ring, and as stepping the thicknesses by eighths and sixteenths of an inch did not follow the increasing pressures well and led to waste of metal it was found more economical to adopt ship-plates whose thicknesses vary by steps of 1/20th of an inch rather than the normal structural plates. The minimum plate thickness adopted was 0.40 in. and the maximum was 1.25 in. The vertical joints between the plates forming the top ring consisted of double riveted butt joints with internal and external covers. Below the top ring and down to three rings from the bottom, the vertical joints were formed by triple riveted butt joints similar to those adopted for the penstocks. Joints in the bottom three rings were made by using the rather uncommon quadruple riveted butt joint where the rivets in the two inner rows on each side of the joint are at half the pitch of the rivets in the two outer rows. The inner cover straps were approximately double the width of the outer cover straps and caulking was done on the edges of the outer covers where the rivets were closely spaced, and on all rivet heads. The rivet diameters varied from $\frac{3}{4}$ in. at the top to $1\frac{1}{4}$ in. which were used for the bottom four rings. The joint efficiencies achieved for the quadruple riveted joints varied from 84 to 86 per cent and the triple riveted joints gave efficiencies varying from 81 to 84 per cent. Some initial difficulties were experienced with the driving of the $1\frac{1}{4}$ in. diameter rivets at site but these were soon overcome, and this diameter appears to be the largest that can be satisfactorily driven through layers of thick plates by ordinary pneumatic hammers.

The base of the tank was supported on a series of short radial steel channels firmly embedded in the concrete foundation in the form of a ring grillage. Horizontal water thrust at the base is transferred through a series of folding steel wedges to the channels of the grillage. The use of folding wedges was adopted to enable the base of the tank to be set truly to the circle during erection, in order that the load should be uniformly distributed through the grillage to the concrete foundation.

The joint between the steel tank and the concrete base was simply and effectively achieved by forming a small V-shaped chase between the concrete and the steel around the inner face of the tank, the chase then being caulked with bitumen. This form of fixed connection between the steel tank and concrete base, which obviates cracking and leakage, had previously been satisfactorily used in two other large surge tanks and a detail illustrating the main features of the connection is given in the accompanying diagram.

At the top a light steel circular walkway supported on cantilever brackets was provided and access is gained by flights of vertical steel ladders of the safety type, securely fixed to the side of the tank. A light circular runway track was suspended from the brackets below the walkway to support a moveable cradle for use in maintenance of the external paintwork. A lead base paint was used for the outside surface of the tank and the inside was painted with bituminous material.

Underground Power Stations: from p. 236

station is underground the excavation of large rooms is undesirable, and therefore the cones are controlled by vertically hinged doors.

The underground discharge pipe is connected with the Adda river. At the end a detachable weir is provided for testing the machines and to control their operation. Provision had been made to drain the canal when required. Fig. 16 shows the alternator room.

Pressurised oil cables convey the energy at 150,000 volts to the outside transmission lines.

Turbine Efficiency Formulae: from p. 237

where c ($= b/a$) and f are experimental non-dimensional coefficients while k is the mean height of the excrescences on the internal surfaces of model and prototype.

Formula (7) involves the "Prandtl—von Karman" expression for rough turbulent flow in pipes and requires a determination of roughness k in addition to the two coefficients c and f. It is thus more complicated than (3). Professor Moody has also given a simplified form of (7) in which $a = o$, and $f/k = 800$.

$$\frac{(1-E)}{(1-e)} = \left(\frac{\log 800\,d}{\log 800\,D}\right)^2 \qquad \text{(7a)}$$

This of course is open to the same objection as (1a) in that it does not allow for the "design" of the turbine.

Energy Resources of the World

We summarised in our last issue some of the papers at the Fourth World Power Conference (held in London in July, 1950) which dealt specifically with technical hydro-electric matters. In dealing further with the conference under the title of "Energy Resources of the World", we give a summary of the water-power potentialities as revealed by National reports.

A GENERAL survey of energy resources and power developments since 1924 was provided in a series of National reports; these papers came from 26 countries, representing almost 30 per cent. of the world's area and 40 per cent. of its population; but in the discussion Sir Harold Hartley said that they covered, in fact, 70 per cent. of the world's production. He added that one-half of the world's total power resources, as far as can be ascertained, were situated in the territories of the U.S.S.R. and the U.S.A., while the remaining half was shared among no less than 50 other countries. The only major absentees from the team of National Committees which supplied reports to the conference were the U.S.S.R., Japan, China and Germany; these countries are estimated to produce about 25 per cent. of the world's total electric power.

National Reports: Scandinavia

Norway was the first country under review, and here it was seen that the all predominating energy resources came from the use of water power. Over the greater part of the country the precipitation was mostly snow, and consequently the minimum stream flow took place in the winter time when the need of electric energy was at its maximum. Norwegian engineers had to devote much of their attention to the provision of storage, and the enormous lakes in Norway were thus of the greatest importance to the power development of the country. Some of them were located at high altitudes and form natural reservoirs which were easy to regulate without damage to cultivated areas.

The latest figures for the possible water power development of Norway are 12,000 MW as an all-year regulated low water capacity. Storage reservoirs of about 1,600,000 cubic feet are needed, and at the moment about one-third of this storage capacity exists. The present installed plant is about 3,000 MW, and this capacity represents about 16 per cent. of the total estimated resources. Only one per cent. of the generated energy comes from thermal power plants. It is interesting also to note that Norwegian manufacturers can produce more than 95 per cent. of the water wheels needed for the power plant expansion programme.

Sweden. Again the vast majority of the energy used is generated by water power, with only 7 per cent. produced by thermal plants. It is estimated that while there is water power available and still undeveloped to give more than 100,000,000 kWh a year, only some 50,000,000 kWh is capable of economic development. Consequently, if the present rate of increase persists all economically available resources are likely to be utilised by the end of the 1960's. The present capacity of developed water power plant in Sweden is about 3,000 MW and another 1,500 MW is under construction. Particular technical features of Swedish water power development relate to the use of underground power stations with long outlet tunnels and to the necessity for very long transmission lines operating at ultra-high voltages, since most of the water power resources are located in the north and the industrial areas are some 600 miles to the south.

Finland started to harness its water power resources comparatively late, i.e., in the 1920's, but there has been rapid development since then. About 65 per cent. of the electricity generated in Finland comes from water power. There have been many difficulties through Finland's wartime situation in carrying out the programme of water power expansion which it was hoped would take place, but by 1952 there should be available about 4,600,000 kWh of water-power-produced energy a year. The programme at the moment shows that 390 MW of new plant is either under construction or has just been completed, generally of the run-of-the-river type, operating at relatively low heads. It is expected that the final development of the present programme, which should be completed in 1954, will give a total of 1800 MW of plant, utilising 54 per cent. of the economically possible sites.

Denmark had to report that there was practically no possibility of developing more than the very small quantity of water power already partly utilised, producing 21,000,000 kWh a year — it is thought that this small production might be about doubled. The country is not favoured with other sources of power, such as coal or oil, and thus is dependent upon imported fuel for her electrical energy; but it is interesting to note that a proposal is on foot to transfer hydro-electric energy from Norway, *via* Sweden, by submarine cable. No plans, however, have yet been announced.

The British Isles

Surveys of water power resources can be regarded as complete. They show that about one-sixth of the total energy requirements at the present time can be obtained from the full development of all economically suitable water power sites. Schemes in the Scottish Highlands, which were estimated to give 6,300,000 kWh per annum, are likely to provide considerably more power as a result of later investi-

gations by the North of Scotland Hydro-Electric Board. The total electrical energy requirement for Great Britain in 1949 was 44,784,000 kWh.

North Wales has small resources of water power and it is hoped ultimately that 360 MW may be installed there. In the Lake District 55 MW appears to be the total capacity that could reasonably be developed. The Severn Barrage Scheme which has been considered on many occasions would give an unregulated output of 2,365,000 kWh per annum, about 6 per cent. of the present electricity consumption, but no decision yet has been reached as to whether the vast capital expenditure attendant on this scheme should be undertaken.

Northern Ireland claims little in the way of hydro-electric development. In Eire there is a limited amount of water power, the total of which is being investigated; but the total theoretical capacity of the sites already developed or in the course of development is 118 MW, corresponding to an annual output of 1,038,000 kWh. Eleven potential sites, in which small power stations might be economical, are being considered, and it is thought that 45 MW might become available. It is estimated that the total development of sites in Eire will produce an output of between 900 and 1,200 million kWh per annum.

Continental Europe

The Netherlands reported that only a very small amount of water power was available, the principal reliance being placed upon thermal production from locally produced fuel. In Belgium also a very small proportion of power comes from hydro-electric resources, and it is not likely that more than 140 MW can ever be developed, even if some economically doubtful projects are carried out.

In France water power provides just over half the total energy requirements of the country. The insufficiency of local coal has caused French engineers to develop extensively their hydro-electric resources; but thermal power plants are still indepensable for the regulation of seasonal fluctuations in hydro-electric production.

There have been many estimates of French hydro-electric resources, but the figure of 60 x 10^9 kWh is given in the French report as a reasonable mean figure. It is suggested that the utilisable resources exceed by five times the present hydro-electric production which, at present, gives an energy output of 13 x 10^9 kWh a year. One of the characteristics of French hydro-electric plant is the preponderance of run-of-the-river schemes. Only about 16 per cent. of the hydro-electric plant, representing less than 8 per cent. of the total consumption, comes from stations with reservoirs which can be used from one season to the next to compensate for an exceptional drought or for seasonal variations. It is noted that the reservoirs in general do not allow sufficient storage capacity to compensate for a very dry year.

The French report also dealt with hydro-electric resources in the colonial territories. In Morocco, about half the energy production, which in 1948 reached 380,000,000 kWh, comes from hydro-electric sources, and further plants are being added. There is little hydro-electric development in Tunisia or in French West Africa, but in the Cameroons there are hydro-electric resources greater than those of the Mother country; for example, on the Sanaga river there is a flow of 17,660 cusecs against 4,950 cusecs on the Rhone at Genissiat. There has, however, been little hydro-electric development in this area. Again, in French Equatorial Africa where it adjoins the Belgian Congo, there is the possibility of developing hydro-electric power on a very big scale; indeed it is suggested that this territory might be a site of the most powerful hydro-electric plants in the world. A number of waterfalls are relatively easy to develop, and in the Brazzaville district a plant of 30 MW capacity is under construction. In Madagascar there are also very large resources, which again are described as exceeding those of France; a number of them could apparently be easily developed. In Indo-China steps are being taken for a plant at Danhim, where a 750 metre head will be harnessed to provide 250 MW of plant for constant generation throughout the year.

From the Iberian peninsula only Portuguese water power resources were discussed. The potentialities at present known total 7,965,000 kWh during years of average rainfall. Of this the northern streams will contribute 76 per cent., those in the centre of the country 22 per cent., and the southern streams only 2 per cent. The flow characteristics of the Portugese rivers are torrential; moreover, the maximum and minimum flows generally occur simultaneously throughout the country, leaving no other alternative for the regulation of the streams but the creation of expensive storage systems.

By the end of 1950 it is hoped that water power plants will reach 75 per cent. of the power plant capacity of Portugal, and the Hidro-Electrica do Zezere and the Hidro-Electrica do Cavado have a number of schemes in the course of construction.

The total hydro-electric capacity at the end of 1949 was approximately 1,600 MW producing about 450,000,000 kWh a year. This compares with a total plant capacity, at that period, of about 350 MW. A high tension network operating at 150 kV, and comprising more than 370 miles of lines, is under construction.

In view of the singularly favourable topographical and climatic conditions in Switzerland it is natural that Swiss engineers have developed a very large proportion of the abundant water resources at their disposal, particularly as there are very few indigenous sources of fuel; indeed, the whole economy of the country is vitally related to the proper management of water power. Great care has been taken to investigate the possibilities of storage in order to produce the maximum amount of energy in the winter, and every part of the country has been surveyed for this purpose. It is thought that a total exploitation, using every possible source in Switzerland, would provide plants having a combined capacity of 7,500 MW, giving a mean annual production of 27 x 10^9 kWh.

Apart from very small plants there are at present 289 hydro-electric stations in Switzerland, having between them thirty-three reservoirs; the present capacity is 12 x 10^9 kWh a year, which represents about 45 per cent. of the total potential resources. The largest station in Switzerland is at Innertkirchen, where 210 MW of plant is installed, and the highest head utilised is at Dixence (1,746 metres).

In Austria, the largest energy resources are comprised in its water power which has its origin in the high level of precipitation and the great differences of head to be found in waters in the Austrian Alps. Plant producing an annual output of about 40 x 10^9 kWh is considered to be feasibly possible of development; about one-eighth of this plant is already installed. Storage is an important matter as many of the sources of water power are purely seasonal. The Alpine water resources in Western Austria have been developed in consequence of favourable geographical circumstances, although the principal area of consumption is in the industrial east. Further development, however, is likely to take place in the lower Alps which are nearer the main consuming area.

In Hungary 94 per cent. of the present electrical power requirements are supplied from thermal stations using coal mined locally. There is also oil and natural gas, and although hydro-electric energy has so far played only a minor part, the potentialities of the Danube and the Tisza have been explored and have been found to give potential power of 230 MW, at "Q95" which the International Electro-Technical Commission defines as the natural or present flow available 95 per cent. of the time. At the corresponding "Q50" figure, i.e., natural or present flow available 50 per cent. of the time, the output of the projected stations on the Danube and Tisza rivers would be 1,043 MW.

Conditions in Czechoslovakia are somewhat similar to those in Hungary since coal, brown coal and lignite exist and provide the source of power for the majority of the central stations in the country. In 1948 only 12 per cent. of electrical output was generated by water, and this figure is unlikely to increase abve 20 per cent.

Italy is another country in which water power plays an important part, but nevertheless she is finding that the limit of utilisation from an economic standpoint is within sight. By 1949 40 per cent. of the estimated usable water power resources had already been exploited, and not all of the remaining are economically practicable.

A large-scale construction programme is at present in being which envisages the harnessing of 82 per cent. of the economically usable water power resources in Italian territory. The present stations provide a total of 21,984,000 kWh a year, and the increase in demand is between 7 per cent. and 9 per cent. a year. Again, as in Switzerland and France, the construction of reservoirs is of vital importance because of the seasonal nature of the flow of many of the streams on which hydro-electric plants are situated. The reservoir capacity in Italy at the end of 1948 corresponded to a storage of 2,735,000 kWh, and installations in the course of construction bring this total to nearly 6,800,000 kWh corresponding to 18.3 per cent. of the annual hydro-electric production.

In Yugoslavia there is as yet little utilisation of the 1,851 streams which have been surveyed for water power. The latest estimates show that at mean water their capacity appears to be about 14,000 MW, and that the power capable of being economically developed amounts to about 9,000 MW, with an output of 45 x 10^9 kWh per annum. There is a considerable programme of development. The latest figures of installed capacity relate only to 1938, and these showed that 168 hydro-electric plants, having an installed capacity of 160 MW, were at work in that year.

The picture presented by the study of the natural power resources of Greece showed that water power development is important since there is only a small local supply of lignite or other fuel; yet the power at present used in Greece comes very largely from thermal stations using imported fuel. The water power resources have been thoroughly surveyed, and it seems that there is ample power potential to cover any future needs of Greek industry. Greece is a mountainous country with precipitations varying from 43 in. to 33 in. on the western coast, and from 20 in. to 16 in. on the eastern coast.

It is estimated that the available water power will produce 4,262,000 kWh a year, but of this only a small proportion has been developed. The latest figures given were for 1940 when 55,000 h.p. of hydro-electric plant was in operation. The total potential energy is divided into a very large number of small catchments, including Crete. A total of 37 schemes has been planned; individual mean annual power productions range from 742,000,000 kWh down to 1,000,000 kWh.

Africa

The next group of papers related to the African Continent, the first country being Egypt, which was reviewed by Dr. Abdel Aziz Ahmed Bey. He recalled that Egypt does not possess natural waterfalls or coal, and electric power produced by oil fuel consumed about double the home production. Thus Egyptian engineers had turned to the river Nile as a source of power, and although at the moment no great amount of power was taken from the barrages at Esna, Nag Hamadi and Assiut there was a very great project under way at Aswan, where a large dam had been constructed for storing flood water and was now to be used to generate power. The station would have a total installed capacity of 344 MW which, under present hydraulic conditions, could give a maximum output of 260 MW practically throughout the year except during the flood period when it would drop to 100 MW, the practice being to reduce the water level in the reservoir during the flood season. The total energy available would be 2,106,000 kWh and would be transmitted at 275 kV to Lower Egypt. There was, however, a proposal to build industries, such as fertiliser works and steel works, near the site and these would be so designed as to allow for profitable utilisation of the output of the Aswan power station in relation to its seasonal fluctuations.

An interesting further scheme which is under consideration concerns the Qattra Depressions of the Libyan Desert. This great natural hollow is situated in the northern part of the desert, having a length at sea level of 186 miles and a width of 89 miles, and an average depth of 197 feet. The lowest point in the depression is 440 feet below sea level. The suggested scheme envisages conveying water from the Mediterranean, some 50 miles away, first by means of an open channel and then by a tunnel to the edge of the depressions where the water would pass through turbines into the low lying land, form-

ing a salt lake. This would then be maintained at its normal level by evaporation. It is suggested that saturation point in regard to salinity would be reached in 160 years, after which salt would be deposited. The projected output of the station is 300 MW, with an annual energy production of 1,968,000 kW. The energy could be transmitted by a 275 kV line 125 miles long to the densely populated area of the Delta. The lake formed by this scheme would also be of service for irrigation, and would create a vast cultivable area.

The final scheme discussed in the report related to the Second Cataract hydro-electric scheme at Wadi-Halfa, where it is suggested that a station of 520 MW and 3,620,000 kWh per annum could be erected. This scheme is under intensive study.

Hydro-electric production in Algeria in 1949 amounted to 145,000,000 kWh, compared with 515,000,000 from all sources. No complete survey is available, but figures show that sources of hydro-electric power totalling more than 10^9 kWh are likely to be available. Development so far has taken the line that new hydro-electric production should roughly equal new thermal production, but a considerable programme of development is now in the course of construction, and it is hoped that by 1952 the total production of energy will be 700,000,000 kWh, of which 325,000,000 kWh will be produced by hydro-electric plants and 375,000,000 kWh by thermal plants. One of the most important schemes which it is hoped will be in operation by 1952, is the station at l'Oued Agrioun which comprises a barrage 246 feet high and 1,608 feet long (capacity of 5,300,000 cubic feet), with a station of 24 MW at the foot of the barrage, and a further underground station lower down in which will be installed two 40 MW machines.

In the southern part of the African Continent, the Union of South Africa has coal as its main source of power. There is little possibility of developing water resources because of the seasonal rainfall and the fact that facilities for economical water storage are lacking over the greater part of the country.

India

The sub-continent has coal and water power as its chief natural resources, and both of these exist in abundant quantity. There is no authoritative and comprehensive survey of the Indian water power resources, but it has been estimated that the ultimate potential may amount to 25,000 MW. The total capacity of investigated sites is 8,500 MW, but at the moment no more than 500 MW has been developed. Projects likely to be implemented within the next ten years will probably total over 2,500 MW, and there are large-scale governmental plans for further development in all areas. Extensive hydraulic storage works are necessary in view of the seasonal nature of the flow of many of the rivers of India. The paper from Pakistan did not make any mention of hydro-electric resources, the author having concentrated on a survey of the available coal reserves.

Australia

Here there are both solid fuel and water power; coal reserves are sufficient for a long period, but water power suffers from the fact that many parts of Australia have a rainfall level as low as anywhere in the world, and there are heavy seasonal and annual variations. The water power potentialities of Australia, however, are by no means negligible, and in various territories there are a number of schemes either completed or in the course of construction.

In Queensland there is very little water power development, but in New South Wales work is proceeding on a large scheme in the Snowy Mountains region. Here seven dams and 16 power stations, giving a capacity of over 2,800 MW, with the power being transmitted by an extensive high voltage overhead system between the Snowy Mountains area and Sydney and Melbourne about 250 miles away, are being planned. Hume Dam was erected 18 years ago, and it is now suggested that by raising the level, hydro-electric plant of 50 MW could be usefully employed. The Clarence river, Shoalhaven river and McClay river schemes, which are under investigation, are estimated to produce 400 MW, but the remaining rivers of the State are not likely to be worth more than 180 MW from the point of view of hydro-electric development.

In Victoria there is a small amount of hydro-electric generation in the Sugarloaf/Rubicon area, and on the Kiewa river 329 MW of plant is under construction in six stations, while the Mitta river and its tributaries are likely to produce 800 MW of power.

There are no possibilties of water power development in South Australia or Western Australia; but Tasmania, having practically no coal, has a very large amount of water power; in fact, although its land area is only 1 per cent. of the whole of the Australian Commonwealth, nearly 80 per cent. of the total available water power resources exist in the Island. At arithmetic mean flow the figure of 1,250 MW is given as the practicable water power resource of Tasmania, provided that requisite storage for reclamation is available. To date there are five major power stations producing 194 MW, and the development now under construction will bring the total installed capacity to 378.2 MW.

The Australian report also includes Papua and New Guinea where there are very considerable water power resources, which in both cases have only been partially surveyed.

North and South America

Hydro-electric interest naturally focuses on Canada, a country which is extremely fortunate in regard to its natural resources of coal, oil and water. Water power has been the principal source of energy for the industrialisation of the country during the present century. Adequate precipitation and favourable topography provide numerous rivers on which falls and rapids, supplemented by lake storage basins, offer frequent opportunities for power development. Computed to the end of 1948, the favourable gross capacity is estimated at 25,000 MW at Q95, and 47,000 MW at Q50. Only 20 per cent. of the resources have been developed, and not all streams have yet been fully surveyed.

In the United States coal continues to be the greatest single source of energy, and reserves cause no anxiety. Estimates of potential water power have

more than doubled during the last 20 years, and with the possibilities of integrated river development and extensive water control over vast areas, it appears that only 16 per cent. of the presented estimated total has so far been developed. An estimate at the beginning of 1949 showed the potential water power resources to be 26,612 MW at Q95 (corresponding figures at Q50—55,207 MW; and on mean flow—84,856 MW); in 1948 only about 16,600 MW had been developed. Great attention has been given to the design and operation of reservoirs which serve harmoniously the functions of navigation, flood control, irrigation, and power; the operation of these reservoirs can sometimes be co-ordinated.

Chile showed that there are very great water power resources to be harnessed—it is estimated that at Q95 about 7,500 MW could be made available. The topographical features of the country provide for continuous production of power, since sites for run-of-the-river schemes are available with a capacity approaching 50 per cent. of the total, while other sites are so situated as to allow the possibility of regulation by means of the large lakes which exist on the Chilean rivers. Thus if energy can be transmitted north and south by a high tension network coupling run-of-the-river plants and those of the reservoir type, seasonal variations can be cancelled out.

OBSERVATIONS

In the discussion on these papers Mr. J. Eccles (Chairman, Merseyside and North Wales Electricity Board, Great Britain) said it was obvious that natural sources were being drawn on, in many cases, faster than they could be replaced. He and other speakers, including the chairman, declared that the wisest use must be made of the energy available, since the various surveys showed that while power resources of oil, coal and water were not unlimited, the very high rate of increase in demand in practically all parts of the world was expanding.

It was notable that very little reference was made to tidal schemes. In fact, Mr. H. Headland (Great Britain) said that only five papers referred to such schemes at all, and in some of these the references were very brief. He thought that the cost of generating power by the Severn Barrage scheme would now be comparable with the cost of thermal energy. French tidal schemes were fortunate in that thermal stations and sites of tidal power development were more closely integrated than they could be in Great Britain.

Control Equipment and Protective Gear

By G. JANCKE and L. IVEBERG, Swedish State Power Board Stockholm. Because of the subject's special interest to our readers, we include an extended summary of a paper presented to the C.I.G.R.E. meeting, which was held in Paris immediately before the World Power Conference.

RELIABILITY of hydro power stations, the authors asserted, rests largely on the design of control equipment and protective gear. By concentrating on control switches, protective relays, and annunciators at a central point, the best supervision conditions are obtained with minimum attendance.

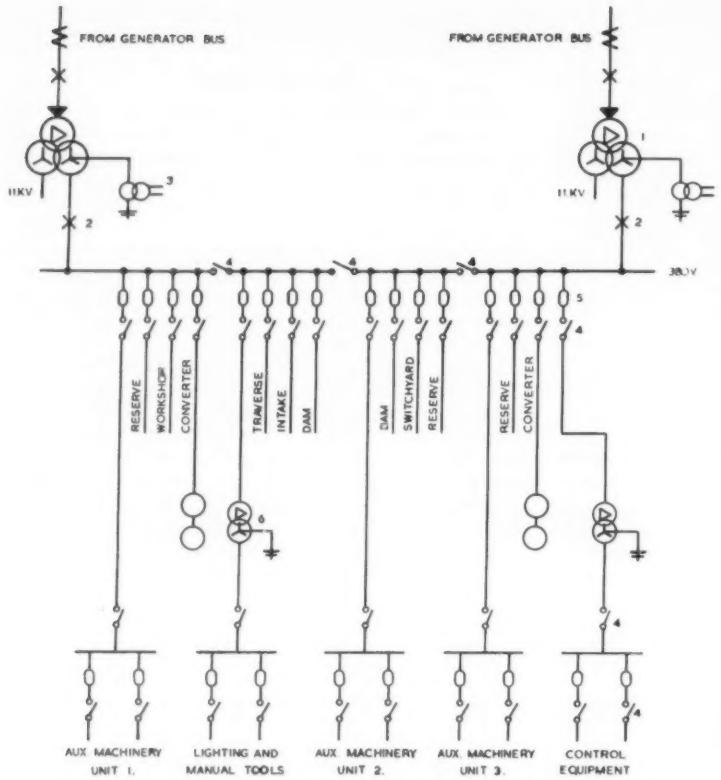
The first section of the paper dealt with auxiliary supply, and it was stated that storage batteries were used in all power and transformer stations, and that although the authors aim to limit the load, nevertheless, auxiliary machinery of great importance is fed by d.c., particularly in view of the necessity of being able to start the station when it is at a standstill without external help. Control, protection, and signal equipments are supplied with d.c.

For the a.c. supply used by the principal auxiliaries, there is a choice of a station transformer, a station generator, and a supply from outside the station. Swedish practice is to arrange for two of such alternatives to be used at each point, each independent of the other. The turbine driven alternator for auxiliary use only involves higher capital costs than other schemes, and, therefore, is relatively seldom used. Further, owing to the Swedish climate, difficulties from ice blocking on small turbines sometimes results in lessened service reliability.

Station generators driven from the main unit shaft are sometimes used, but normally auxiliary transformers are employed, connected as shown in the diagram. The auxiliary voltage is 380 volts 3-phase, but large loads remotely located, such as dam gates, are fed at 11 kV from special step-up transformers. The 380 volt system has an insulated neutral, so that an earth fault does not necessarily necessitate tripping.

The storage battery for the d.c. supply operates at 220 volts, although for single circuits, a separate battery, with a voltage which in different stations varies between 24 and 110 volts, is used. In parallel with the main battery is a rotary converter or a rectifier of a size to carry the whole of the normal load plus a trickle charging feed for the battery itself. Two such rectifying devices are used in each station, one as a standby to the other, and in a large station with three main units a 100 kilowatt converter has been used with a battery of 456 ampere-hours capacity at the one hour discharge rate. The very largest stations have two batteries. The d.c. systems are operated insulated from earth, and a relay supervises the state of the insulation, giving alarm when needed.

Turning to the subject of instrument transformers, current practice in Sweden is to separate the current transformers from the breakers and to place them



Connection diagram of 380 V a.c. head central in a water power station. 1, station transformer; 2, air breaker; 3, voltage transformer for ground fault supervision; 4, knife switch; 5, fuse; 6, intermediate transformer 380/220 V.

outside of bypass devices, so that in taking a breaker out of service relay settings or current transformer circuits need not be altered. It is then only necessary to lead the tripping impulse from the relay section to the reserve breaker. Voltage transformers are connected to the lines, but at over 130 kV, capacitor type voltage transformers are used, which also serve to connect carrier current devices to the line and contribute to the surge protection of the station.

Another section of the paper dealt with control equipment, and first the authors stated that the control room is generally placed on the same plane and next to the machinery hall, thus permitting the same operators to supervise the machines by direct inspection, and also to check the switchgear control panels. There are two attendants in most of the hydro stations, one of whom spends the whole of his shift in the control room, while the other inspects the plant at regular intervals. The larger hydro stations of the State Power Board are generally so located that the attendants are needed not only with regard to the operation of the station itself, but also for the supervision of waterways and the operation of distribution and transmission systems. Thus it has not proved economical to design any large power station for entirely automatic service, or remote control, but this scheme is used on occasion for switching stations, and for some of the smaller power plants.

In a section dealing with the protection of hydro generators, the authors stated that the most serious kind of generator fault is the destruction of the stator laminations and the risk of this is lessened considerably if the neutral is grounded through a resistance limiting the fault to 15 amperes at single-phase fault. This resistance is generally connected to a secondary in the transformer of the neutral, and is made temperature-dependent and for continuous duty. A generator subjected to stator earth fault is tripped by means of neutral voltage protection supervising about 95 per cent. of the winding. Instantaneous differential relays constitute short circuit protection, and schemes are available whereby a fault current as low as 1 per cent. of rated generator current may be detected and made to cause tripping. Protection of the conductors leading the current away from the generator takes the form of split conductor protection with transverse-differential relays, and in certain stations, which feed long high tension transmission lines, over-voltage protection is installed. Thermal overcurrent protection is inserted in one phase. Fire protection is accomplished by means of thermo-sentinels with fuse strips and attached nitrated wires being suspended at the ends of the winding. Rotor protection is achieved by the injection of a.c. current from an auxiliary source through capacitors to the two sides of the rotor, with a relay which detects any unbalance between the two thus indicating incipient insulation failure. Transformers are provided with differential protection design not to react to inrush current.

Distance relays are used for transmission lines of higher voltage than 55 kV, and at 220 and 380 kV this system is combined with high frequency carrier equipment. The principle of operation is such that the first step of the distance relays comprises 125 per cent. of the protected line, and the high frequency equipment prevents tripping at both ends of the line during 0.5 of a second if one of the distance relays should have moved to the locking position.

An annunciator is placed on the control desk to which all signals are brought which require the intervention of the operator. Amongst these are (for each turbine): signals for oil level, oil pressure, oil circulation, leakage water, runaway, link fracture, and temperature of bearings; and for each generator: oil level; oil pressure and temperature of different bearings; temperature of windings; circulation in cooling radiators; position of mechanical brakes; operation of conductor protection and earth fault protection of the field circuit; troubles concerning the voltage regulation; the electrical side of the turbine regulation; carbon dioxide release for fire protection; and finally, bearing current indication.

There are also signals for dam gate intakes and various other important levels, and similar indications.

Electrical System Protection

The Editor, who recently visited the works of Brown Boveri and Company Ltd., describes some recent developments in high voltage switchgear and ancillary devices at Baden, Switzerland.

THE ever-increasing demand for electrical energy entails the production of more generating equipment and sub-stations of greater and greater size, as well as extensions to associated overhead transmission lines and distribution systems. This, again, involves switchgear of higher and higher breaking capacities and of maximum reliability and simplicity if the power produced, perhaps at some remote hydro-electric station, is to be available with the minimum of interruption throughout the service area.

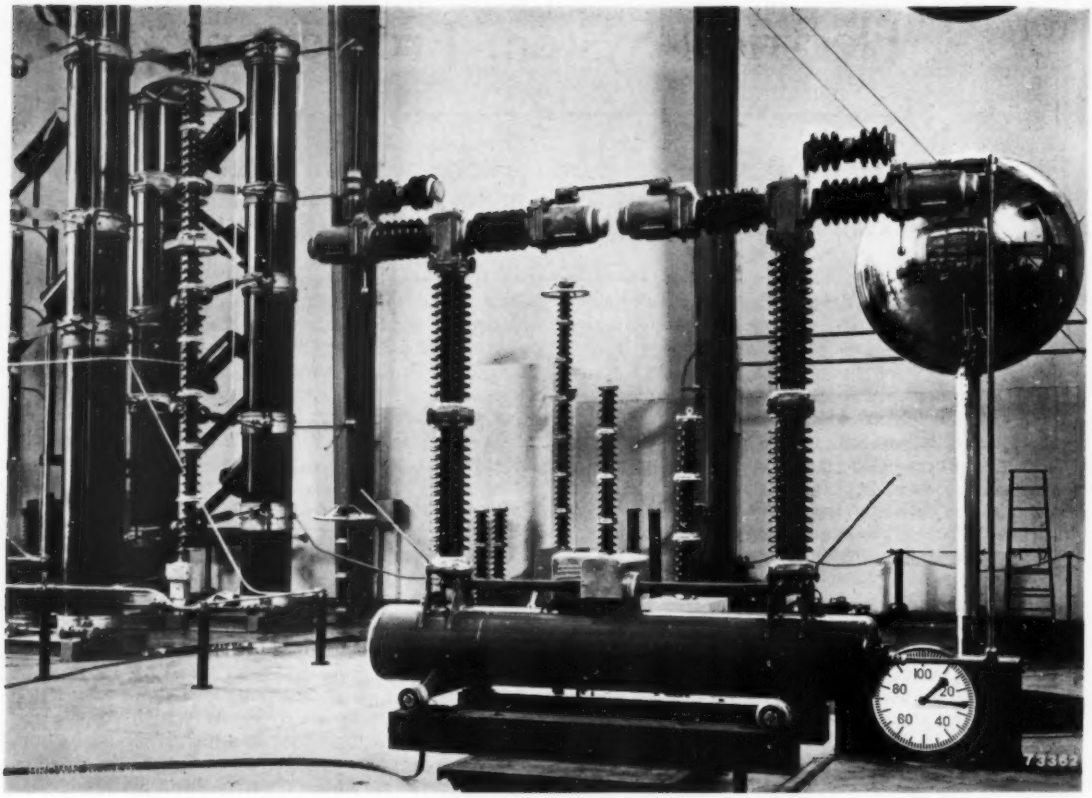
For its efficient operation the system depends largely upon devices which protect the electrical installation as a whole, and recent progress in this most important sphere was discussed at an Electrical System Protection Meeting arranged by Brown Boveri and Company Ltd. and held at the company's Baden (near Zurich) works at the end of September. In 1946 a similar meeting was held, when visitors were invited to see equipment which had been developed during the war period when Switzerland was more or less cut off from the rest of the world and it had been difficult to keep in touch with customers abroad; at that time a new range of indoor circuit-breakers with ratings up to 30 kV and 1,000 A was demonstrated. Since then work has been concentrated on extending the range to 60 kV and 4,000 A, and to evolving a class of outdoor breakers for the entire 80—400 kV range based on new principles. Operating experience with more than 10,000 indoor and 1,000 outdoor circuit-breakers, many of which have to satisfy extremely arduous service conditions, frequently under severe climatic conditions, has gone into the advanced designs, and some of them were demonstrated during the recent meeting.

The latest outdoor air-blast breakers, which have been developed to meet all possible system requirements, including the highest voltages yet considered, are based on the principle of potential-controlled multiple breaks introduced by Brown Boveri some ten years ago. In this way circuit-breakers can be designed for any desired requirements and tested to practically full breaking capacity in existing high-power testing plants, which is of importance since the installation of the requisite plants has been outpaced by the rapid increase in breaking capacity of switchgear at the highest voltages, and there is now practically no possibility of making tests at the full capacity, except in actual systems. With the multiple break, the most important moving part of which is the nozzle tube with its built-on exhaust valve, each arc extinction chamber is subjected only to part of the total voltage stressing so that its breaking capacity is considerably lower than that of the complete circuit-breaker. If the voltage distribution during the switching process is known, each chamber can be tested for that part of the interrupted power with which it has to deal, and the result will correspond to a test on the entire breaker. This was demonstrated when an arc extinction chamber—the most important component in the assembly, to which the compressed air necessary for the extinction of the arc is supplied through a vertical insulator—belonging to a single-phase unit of a 150 kV breaker was opened under short-circuit conditions, the total interrupted power being over 350 MVA. It corresponded to a total breaking capacity of over 4,200 MVA at 220 kV. To show that the breaker functioned correctly under the severest meteorological conditions the breaker was subjected before the test to sudden temperature changes, then sprayed with water in the low-temperature testing station so that it was completely iced up.

The final model of the new outdoor breaker range is, for the time being, that with a 380 kV rating. The chief problems in connection with the construction of this breaker were set by the very high voltage and the long transmission lines to which it would be connected—from Harspranget to Hallsberg in Sweden, a distance of 600 miles. Characteristic features of the 380 kV breaker unit, compared with other models, were, firstly, the changed mounting of the arc extinction chambers, auxiliary contacts, and non-linear resistances to effect voltage distribution—although those components were of the same design as on breakers of lower rating—and secondly the porcelain insulator bracing elements. The altered arrangement is due to the fact that because of the high voltage stressing the distances between individual components had to be made as large as possible, while the bracing elements were incorporated after computation of wind pressure stresses on the large-dimension breaker. The principle adopted was only to employ material where it was absolutely necessary to meet those stresses: bracing members are only stressed in tension, thus enabling their cross-sections to be kept small since there is no risk of buckling of the insulators.

The required breaking capacity was readily attained by applying the controlled multiple break principle. A reclosing cycle was demonstrated on a single-phase unit, once with an arcing fault and then with a persistent short circuit. In the first instance the breaking operation was effected so quickly that the arc had no time to extend beyond its initial length; in the second case the breaker had to interrupt the short-circuit power twice in succession against the high recovery voltage of about 350 kV.

In the section of the factory where the air-blast breakers are made and assembled there was a splendid opportunity for gaining an insight into their design. The main feature of the new outdoor type is its extremely simple construction, in that the isolating switch, its operating mechanism, and all rodding between the individual single-phase units has been



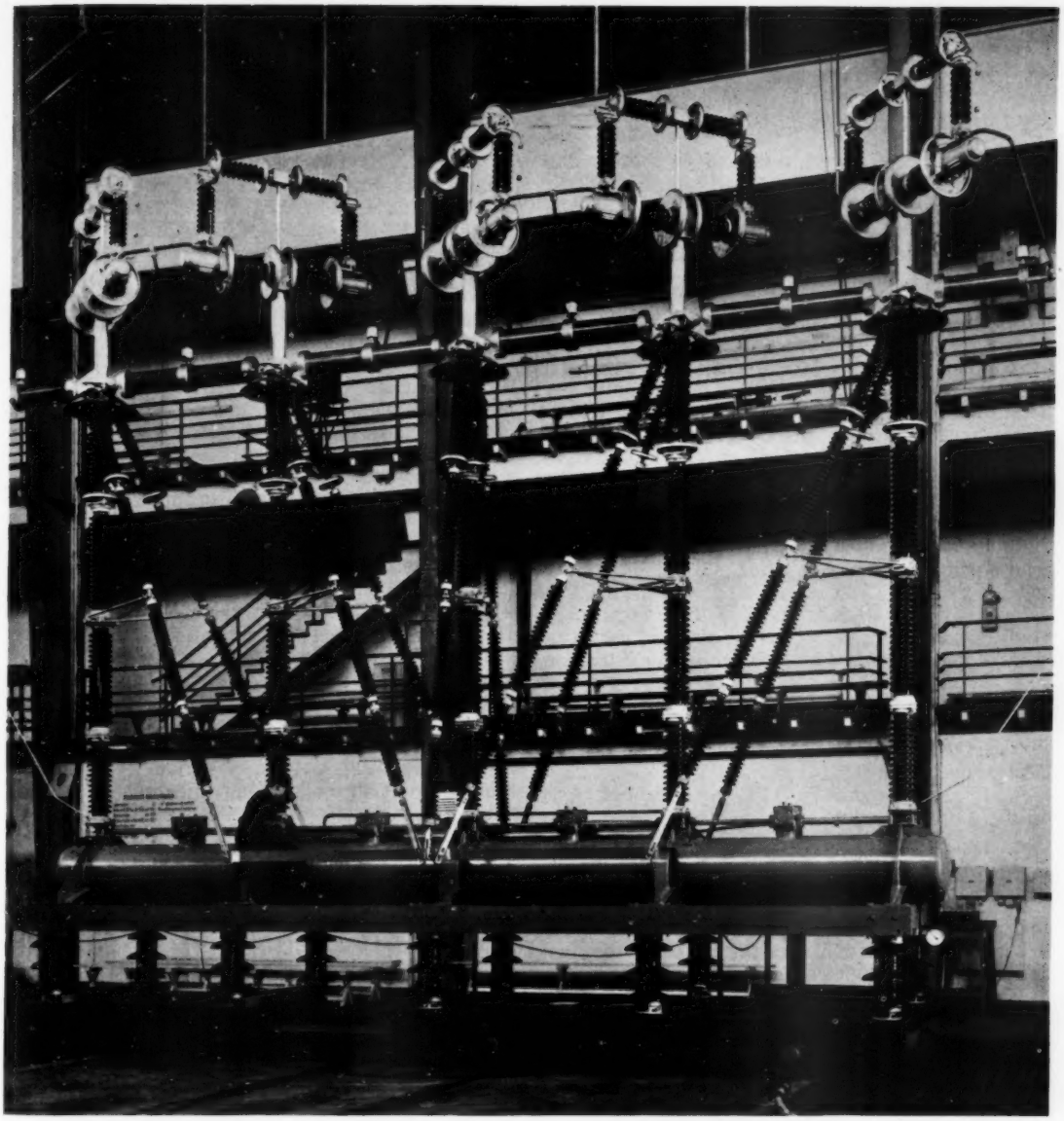
Impulse testing of air-blast high-speed circuit-breaker with 2,400,000 volt impulse generator on left

eliminated. As a result all the problems connected with the isolating switch contacts, such as erosion, lubrication, icing, etc., have been excluded, while foundation irregularities are no longer important because the individual single-phase units are interconnected solely by compressed air pipes and a few control leads. Of particular advantage is the use of standardised components which are exactly the same for all breaker sizes from 80 to 380 kV, with the exception of the air receiver, as the units enable batch production methods to be employed. The simplification thus introduced allows careful individual inspection and testing, while the ease with which spare parts can be stored is also an advantage.

While an electrical system has to withstand the stresses produced by the a.c. load conditions it must also, if the service is to be reasonably secure, be able to contend with exceptional stresses developed by overvoltages and particularly those of a transient nature. The most dangerous of these are those generated in the atmosphere, and unfortunately (for reasons of economy) it is not possible to fix the insulation level of electrical systems so high that flashovers due to atmospheric overvoltages are avoided in every case. They can, however, be made to take place where the flash will cause little or no damage, if it exceeds the discharge capacity of installed lightning arrestors.

At the Brown Boveri works there is an elegant high-voltage laboratory where the stresses set up by lightning strokes can be investigated with the aid of an impulse generator which is capable of producing voltages of the order of 2,400 kV. This impulse voltage, rated to discharge 25 kW/sec., reaches its peak value in about one millionth of a second, thereafter decaying in 200 millionths of a second. The generator was used on many occasions during the demonstrations, one of which concerned the insulation problems associated with 220 and 380 kV systems. Two similar post-insulators were subjected in each case to tests; one being dry and the other wetted by artificial rain. As was anticipated, the flashover occurred on the 220 kV wet insulator; but in the case of the 380 kV insulator, with a distance of 13 ft. (four metres) between electrodes, it was not the wet insulator that flashed over. That unexpected result—the failure of the dry insulator—was due to a difference in field distribution, and an alternative arrangement was demonstrated whereby the flashover strength of the dry insulator was brought up to that of the wet one. A further test on the 380 kV insulator showed that its condition could be improved by an alteration of the arrangement and form of the electrodes. Two 380 kV insulators, one with the conventional annular fitting and the other with a new type designed to avoid brush discharges, were simultaneously subjected to a dry test; whereas the insulator with the annular fitting was seen to flash over at about 850 kV, after heavy preliminary discharges and with the same clearance between electrodes the flashover voltage of the new fitting was over one million volts.

For the final demonstration in the insulation co-ordination research work, a single-phase unit of a



The first 400 kV air-blast circuit-breaker in the world just completed by Brown Boveri. Compare size of mechanic working on the air container

380 kV air-blast breaker, similar to those being supplied for the Swedish 380 kV transmission system, was employed. (The three-phase breaker has a rupturing capacity of 8,600 MVA at a maximum service voltage of 400 kV.) First of all the closed breaker was tested with a voltage of 975 kV to earth—glow discharges invariably occur at such high voltages, but brush discharges were practically eliminated with the new type of electrodes. The same voltage test with the breaker open, whereby the ten series-connected arc extinction chambers in the assembly were stressed by the test voltage of 975 kV, again proved the breaker's high electric strength. Its impulse strength was shown in a spectacular manner, in that the breaker withstood impulse waves of 1,800 kV volts with flashovers occurring only across the spark gap provided for the purpose. The insulation of the series-connected arc extinction chambers did not flash over since the flashover strength of the break is more than two million volts; thus the coordination of the insulation of the 380 kV switchgear was proved.

During this most pleasant and enlightening visit to the Baden works other aspects of the problem of electrical system protection were discussed, including the extensive use of relays, which showed the value of rapid operation and sensitivity when associated with power supply circuits, and the advantages of remote supervisory control through carrier channels for high-speed distance protection.

Concluded on page 258

Book Reviews

Hydro-Electric Handbook

By William P. Creager and Joel D. Justin. 2nd Edition published 1950 by John Wiley, New York, and Chapman & Hall, 37 Essex Street, London, W.C.2. 1950. 1,151 pp. fully illustrated. Price 100s.

The long awaited second edition of this well known compendium, first published in 1927, is now available to the public. One of the first things to strike the prospective buyer is that the price is more than double that of the first edition, a trend which, alas, is only too common these days. However, a mere comparison of price between the two editions is not quite fair because of their great difference in length.

The handbook has been enlarged from 897 pages and thirty-five chapters to 1151 pages and fifty-eight chapters. Whereas the first edition contained articles by eleven contributors inclusive of the authors, the second edition has nineteen contributors exclusive of the authors. Thus it will be seen that the work has been largely rewritten and virtually a second volume added.

Most of the chapter headings in the original have been used again in the second edition and the extra twenty-three chapters mainly cover site investigation and the preparation of foundations, economics and market requirements, details of dam construction and auxiliaries. These are the logical additions, when one considers what the main developments since 1927 have been.

A passage in the preface to the second edition sums up the scope by saying that " Sufficient information is . . . . presented to give the reader an accurate picture of the problems involved and to provide sufficient data for preliminary designs, estimates of cost, and reports, but it will be necessary for the designer to consult treatises on the complete design of individual structures and appurtenances thereof when the final design of the development is to be made."

The book has been divided into four main sections each of about three hundred pages as follows — Preliminary studies and economics, dams and dam construction, conduits and power houses, equipment and operation. Thus it will be seen that an attempt is made to cover all aspects of hydro-electric practice. The contributors are all well known in America, as experts in their fields and it is of great advantage to have such specialist knowledge available.

The work is too large to review in detail but it is hoped that a few general remarks and comparisons with the first edition should give the reader an idea of its value. The first sixteen chapters cover fundamentals needed in the preparation of any scheme, such as hydrology, assessment of plant capacity, economics and market requirements and the submission of reports. The latter is most useful and gives a comprehensive list of all the items which should be covered.

The hydrology is specifically that of America and so can only be used in modified form for other countries For instance, the collection of unusual flood discharges on page 62 comparing empirical formulae and actual flood measurements is based on records of 997 different rivers. Of these only 31 are outside the United States and there is no mention of what country or river they represent. Thus the empirical formulae, although applicable to American floods, may be of no use elsewhere. To most Europeans the use of the term " second feet " instead of cubic feet per second will seem particularly illogical and there seems little to justify its use.

Both hydrology and river gauging seem to have changed little since the first edition. It is pointed out that both in the matter of predicting evaporation losses and flood flows, the best method is to accumulate field measurements over as long a period as possible—yet another illustration that the success of the statistical method depends entirely on the number and type of observations available for analysis.

The chapter on hydraulics has been carefully revised and the graphs of conduit and bend losses brought up to date. At the end is an additional section on hydraulic models and similarity laws. Bearing in mind the importance of model testing nowadays, this might have been profitably extended.

The chapters on economics of steam and water power have been drawn from "Power Supply Economics" by Justin & Mervine and the latest figures quoted seem to refer to 1947. Such chapters are necessarily restricted by the present economic fluctuations but wherever possible the figures are comparative, with the proviso that costs of hydro-electric schemes are usually underestimated. No mention is made of European literature on this subject. Chapters 17—26 inclusive cover the construction of various types of dam and headworks, the material being taken from the author's classic work " Engineering for Dams." The graphs giving weights of various types of gate are interesting for comparison with practice in other countries.

No mention is made of important European developments such as the French prestressed dams, the Coyne ski-jump spillways or the excellent work done by the Institution of Civil Engineers Research Committee, and at Stockholm on fish passes, to mention only a few.

Chapters 27—30 cover the design and construction of open and covered conduits of all kinds; the new chapter on steel pipes is welcome but there is little said about hooped and prestressed steel pipe. Chapters 34 and 35 are new and deal with water hammer and surge tank problems. Classical graphical and computational methods are illustrated but there is little said about resonance failures. In fact the layman may be given the idea that surge problems are relatively straightforward, whereas a cautionary note should be added on this most important problem. Power house design does not seem to have altered much since the first edition, which is rather remarkable. No mention is made of underground stations.

The chapter on water turbines and auxiliaries gives an idea of standard American practice, but little indication of modern developments. For instance the highest head Francis machine in the United States seems to be 960 ft., which is less than the largest European head (1,640 ft., in Norway). No mention is made of such low heads as 2.7 metres (Vargon, Sweden) being used for Kaplan turbines. No distinction is drawn between air and vapour cavitation.

The fundamentals of electrical design have not altered much, although modern computational aids

such as network analysers have been developed. The wider use of air-blast switchgear is apparent when comparing the two editions and the economics of pylon spacing and transmission lines has been brought up to date. Little mention is made of new developments such as high-voltage D.C. transmission or gas-filled cables.

In general the book is a most valuable collection of data on standard American practice and represents an enormous amount of work in recording the experience of the expert contributors. The preparation of such a handbook involves years of effort and of course, it is quite impossible for a work of this kind to be completely up to date at the time of publishing. It is not known whether the authors have intended to record only standard practice, and to exclude relatively untried developments; it may be felt that such developments are not well enough established, but even then should at least be mentioned as they may be the standard practice of tomorrow.

Little or no attempt has been made to cover European practice, which is regrettable, for there are still many fields where European practice can be said to lead America. Nothing is said of Genissiat and Rhone schemes involving novel methods of dam construction, ski jump spillways, the high head Kaplan turbines of Charmilles, the underground power stations of Sweden, or the "Pfeiler Kraftwerk" of Germany. Such achievements should be at least worthy of mention.

The book is strongly bound and well illustrated and printed. As in the first edition, the inclusion of detachable duplicate graphs for more important items is an excellent feature. Where graphs from the first edition are used, they have been made clearer and improved by plotting in non-dimensional form wherever possible. The value of the book is enhanced by a good bibliography at the end of each chapter, although these might contain more references since 1945. The index at the back of the book is large but not really detailed enough for such a great work and could be profitably extended. The work will be a valuable addition to the library of all hydro-electric engineers, but it is regrettable that its price is so high for it will be beyond the reach of many, particularly students.

S.P.H.

Lexique Technique Francais-Anglais and Anglais-Francais concernant le Materiel de Travaux Publics

Published by the Institut Technique du Bâtiment et des Travaux Publics, boulevard Raspail 28, Paris-VII, 8.2 in. × 5.5 in., 176 pp. At first sight it would appear that the title of this glossary is, in some degree, a misnomer as it is devoted very much more to general technical terminology than, as claimed, to the equipment more especially used in public works. The English reader must, however, realise that, owing to the appalling ravages of the war in France, the term "travaux publics" has now over there a considerably wider sense than "public works" in this country, and, in addition to public works proper, covers practically every branch of industry. The idea of this glossary obviously arose of the necessity to order abroad, and more especially in U.K. and U.S.A. an enormous amount of equipment ranging from handtools to the heaviest castings or pieces of machinery. Across the Channel there must be a flood of specifications and estimates in English, not to mention catalogues, pamphlets, etc., and this glossary undoubtedly meets a most urgent need. As could be expected, more stress has been laid on the English-French section which covers 73 pages against 49 in the French-English section. No fewer than 45 conversion tables are appended, ranging from millimetres into inches to h.p. into kW and vice versa.

Wasserkraftmaschinen und Wasserkraftanlagen

By Keyl-Häckert. Published by Koehler Verlag Stuttgart (1949). 228 pp. 125 ff. Price 7.80 marks. This book deals with the design of turbines and power stations and is intended for the students of German technical colleges; it cannot, therefore, be compared with treatises like those of Camerer, Thomann, Ténot, Bergeron, etc., which exceed by far the standard of college or university lectures. Even so the book indicates that this particular subject is taught with more detailed thoroughness in German technical colleges than is usual in this country; but the book is not up to post graduate standard.

Compared with the second edition of Creager and Justin's Hydro-electric Handbook, this German publication will be found to enlarge on many theoretical developments ignored by the American textbook, which, however, has the merit of being more precise on practical data. The comparison of German practice (to which the author confines himself) with American practice is also valuable.

The book deals with the subject under the following chapter headings: Summary of general hydraulics, brief description of modern hydraulic structures (too short), theory of turbines (impulse, reaction and Kaplan), parts and auxiliaries, description of existing turbines.

C.J.

British Council and the Sciences

The revised form of the annual report put out by the British Council makes more easy this year the study of each major aspect of the Council's work. Its objectives and achievements in the sciences now occupy a chapter to themselves, covering the pure and applied sciences as well as engineering, agriculture and medicine. In all these the British Council's aims have continued to be the closer cooperation of scientists here with those abroad, and the better understanding of Britain by disseminating oversea knowledge of British activities. The work is necessarily restricted because the Government limits the British Council's approach to specialist and educational groups. The Council "neither indulges in scientific propaganda directed towards the general public oversea, nor participates in commercial activities or the advertising of specific scientific commodities." Yet the spreading of knowledge of British methods is thought to cause a not inconsiderable, but generally imponderable, demand for British scientific products.

Besides the facilities provided by its medical and scientific libraries in London, it has libraries oversea which, according to the interests of the country, have sections devoted to the sciences. The Council produces scientific periodicals to give the specialist a deeper insight into current work in Britain — the *British*

Agricultural Bulletin, British Medical Bulletin and, until an economy decision caused it to be discontinued, *British Science News*. A more recent venture, *Scientific Research in Britain*, is to be produced in future by the Department of Scientific and Industrial Research, though the material will continue to be collated by the British Council.

All this is supplemented by an information service, and by distribution of films on scientific subjects to Council centres oversea or to individual scientific bodies.

" Probably more important than the establishment of indirect contacts between scientists and the spreading of information of British advancements in the sciences is the actual interchange of scientists between Britain and other countries," the report comments. Information on these movements is given. The value of the leading scientists who are sent on oversea lecture tours by the Council extends far beyond the formal lectures which they deliver. It is likely that their most important function is achieved in informal discussions, and in some cases by demonstrations in laboratories, hospitals and institutions, where close contact is achieved with the individual scientist and the value of the contact is general as well as scientific. Most universities, learned societies, and other institutions in North European countries agreed during the year that the British Council should coordinate visits by British lecturers in the sciences, whom they themselves invite. F.C.R.

Hydrographical Bases of the Plants and Projects of the Ill Water-Power undertakings

By Alois Kieser; published by Springer-Verlag, Vienna, 1949, 8.2 in. × 6 in., 36 pp., 21 ff. Price 3s. 6d. This report, which previously appeared in " Oesterreichische Wasserwirtschaft " (Water Development in Austria), No. 3/4, 1949, is reprinted here as No. 17 of the publications of the Austrian Water Development Association. It gives a general survey of the organisation and working of the waterflow measurement system set up by the company controlling the Ill River plants (Vorarlberger Illwerke A.G., in Bregenz, Austria). An extensive net of measuring stations at key points on the Ill itself as well as on its tributaries, was set up at the outset, the whole system being supplemented by a number of raingauges provided for daily records in the vicinity of inhabited places, and for annual records at higher points in the mountains, varying in altitude between 6,365 and 10,334 ft. The " Illwerke " were thus in a position to work out their projects, and build their plants, on the basis of an accurate knowledge of the water resources available. G.J.P.

" *Beitrage zur Theorie und Berechnung der Bogenstaumauern* "

(Comments on the Theory and Calculation of Arch Dams). E. Bosshard. No. 22, Mitteilungen aus dem Institut für Baustatik. Federal Institute of Technology, Zurich, 1949. 164 pp. 36 figs. Price 14.50 Swiss francs. In a paper recently published in Civil Engineering and Public Works Review (April-September 1950), the writer has endeavoured to relate the attitude adopted by different schools of engineers towards the problem of designing high arch dams. Summarising the present position, it can be said that the Americans prefer gravity arch dams and are sponsoring the trial-load method. This method consists in dividing the dam into a grid of horizontal arches and vertical cantilevers. At the intersection points of the grid unknown forces have to be applied in order to equalise the deflections of both the arches and the cantilevers. This is achieved by a trial and error method. Both the French and the Italians distrust the American approach, but for different reasons.

The French introduced the " active arches " theory; the Italians concentrate on the technique of model tests.

The contribution of the late Prof. M. Ritter (Zurich) to the theory of arch dams consists in having developed a straightforward method for solving the modified equations of elasticity without submitting to the long trial load method. Ritter died without being able to publish his method. The author, a former student of Prof. M. Ritter, now submits an extended method, based on the ideas of Prof. Ritter. The book under review is not a mere exposé of Ritter's method and ideas, which are dealt with briefly, but an extension and generalisation of them.

One of the most important points consists in a remark on the choice of the fundamental system. Ritter (in accordance with American practice) considered a grid consisting of horizontal arches and vertical cantilevers, built in the elastic rock foundations. The unknown of the system are the elastic loads at the crossing points of the grid. The author remarks that such a system is convenient for dams in wide " U " shaped valleys but gives inaccurate results for high dams in " V " shaped valleys. For this type of dam he replaces the vertical cantilevers by vertical simple beams resting on the horizontal arches. The unknown are the moments at the crossing points of the grid. These remarks by Mr. Bosshard give a possible explanation for the failure of the trial load method in the calculation of very high thin arch dams of the Italian type.

The author develops also complete sets of equations for the calculation of arches with varying thickness, including therein the elasticity of the abutments of arches and cantilevers. This part of the thesis is developed with great care.

Mr. Bosshard's book is an extremely valuable contribution to the modern theory of arch dams and brings new light on to several problems previously unsolved.

C.J.

Continued from p. 255

The overall impression gained as a result of a wide range of demonstrations was that only modern circuit-breakers with short breaking times, combined with carefully adjusted, high-speed and selectively operating relays, could satisfy all the requirements of modern electrical system protection. Indeed, this view was confirmed during a visit to the first Swiss underground low-head hydro-electric power station at Lavey, near St. Maurice in the Rhone Valley, where most of the apparatus demonstrated at the Baden works of Brown Boveri could be seen in practical service at the station belonging to the City of Lausanne Electricity Supply. The Lavey Hydro-Electric Station will be fully described in a forthcoming issue of WATER POWER.

Modernisation of Hydraulic Plants in France

By STÉPHANE FERRY, Ingénieur en Chef au Service de la Production Hydraulique a Electricité de France

OUR readers have been kept informed of the major programme of French hydro-electric expansion, which relates to installations of medium or major importance, these varying in size from 100,000 kW to nearly 400,000 kW, with mean annual productions exceeding, in certain cases, 100,000 million kWh. In spite of this, there has been a considerable effort and expenditure in the direction of increasing production from the smaller existing plants. These plants — of secondary importance in regard to the major programme — are examined, and the subsequent work undertaken by the *Service de l'Exploitation (Production Hydraulique)* in regard to the modernisation and re-modelling of existing plants. Either the *Service de l'Exploitation* or the *Service de l'Equipement* undertakes the installation of additional generating units.

Modernisation of Old Plants

The modernisation schemes are undertaken with a view to secure economies of operation (notably by the reduction of personnel) to assure a much greater security of service and to augment production. All or part of these objectives can frequently be obtained as a result of the same scheme.

Modernisation of remote control of the turbines and the addition of protective equipment were among the first operations undertaken. These modifications affected ten plants, permitting a certain increase in production, and a reduction of eighteen in the personnel required. This was accomplished by an investment representing the annual charges equivalent to the salaries of sixty-five workers. Thus, the investment becomes a paying proposition in less than four years.

The semi-automatisation of hydro-electric stations constitutes a transformation of a more substantial character. This method of modernisation is in course of being carried out in twenty-one small plants. It takes the form mainly of centralising the controls, modernising the instrument boards, and adding the protective devices, both mechanical and electrical, which have been found necessary to permit a reduction in permanent attendance to the level of a single man, who is responsible only for starting up and shutting down the equipment, and for calling on the services of a qualified technician in case of trouble. This solution is, in general, more economic and more certain than supervisory control by telecommunication equipment, or by completely automatic operation.

The work already undertaken in this direction assures, in addition to an augmented production of about 6 million kWh each year, an economy of 55 operating personnel for an expenditure equivalent to the annual salary of about 370 people. In other cases, by means of complete renewal of certain units, the new installations are treated from the start as being semi-automatic in operation.

Complete automatisation or supervisory control by telecommunication are not solutions generally applied by reason of their high cost and the complexity of the automatic equipment, necessitating frequent maintenance and inspection, which may be as costly as the manpower displaced. Nevertheless, one or other solution has been found in the case of seven plants comprising thirteen generating units having a total capacity of 47,000 kVA. By this means it is possible to obtain a staff reduction of 28 men by an investment equivalent to the annual salary charges of 125 men. Particular mention may be made of the plant at Calypso on the River Arc, where two 9,000 kVA units are controlled by supervisory means from the plant of Saint-Michel, 300 metres distant, for an expenditure representing the annual salary charges of ten men, the economy realised in respect of manpower being represented by four men's salaries.

More extensive modifications of old installations may imply total or partial renewal of certain units, with modifications to their characteristics. These changes may include alterations to the number and to certain details of the pipelines.

Renewals achieved since 1948, in course of progress, or immediately projected, relate to 15 stations and 32 units, having a total output of 130,000 kW. The gain in energy provided by these modifications will total 125 million kWh each year. The most important work is taking place at the Tuiliere plant on the Dordogne. This station dates from 1908, and comprises nine units with vertical axis Francis turbines, absorbing 22 cubic metres of water per second under a head of 10.5 metres, the alternators being of 1,800 kW. These nine units were replaced by nine new units having the following characteristics: Kaplan turbines absorbing 52 cubic metres per second at maximum load and driving alternators of 5,500 kVA. The augmentation of the output leads to an increase of 30 millions of kWh per annum, the mean annual production figure now reaching 100 million kWh.

Naturally all these modifications were carried out in such a way as to interfere as little as possible with energy production, and on occasions this necessity caused the changeover period to be greatly lengthened.

Methods of Increasing Production

The most simple of modifications to be effected was to increase the working head to some extent by raising the water level. This super-elevation can sometimes be obtained totally or partially by an addition

to the height of the framework of the sluices. It has been possible to gain an increase of energy output of 32 million kWh annually by the super-elevation of five dams—the increased heights being between 50 and 80 centimetres—at very small expense. Occasionally the installation of an additional unit has been possible in plants where the potential output is not completely absorbed by the existing machines. This has been done at the low-head plant of Cusset, on the Rhone near Lyons. The addition of a fifteenth unit permitted the production of an extra 15 million kWh a year, and further facilitated maintenance operations.

The greatest effort in the programme for production increase is constituted by the addition of new tracts to catchment areas, the precipitation from which is led towards the principal water course or the head-race canal of an existing plant, without modifications to the plant itself. Occasionally the additional water flow is combined with modernisation of the units, and an increase in their power. Ten additions, not of equal importance (of which two included a pumping arrangement) have already been carried out, or are in course of construction, or will be directly undertaken. They permit a supplementary production of 160 million kWh per annum of which 50 million kWh were derived from the River Colagne—a tributary of the Lot—in the valley of the Truyere.

Miscellaneous modifications include a new unit, with independent pipeline, in an old plant already carrying two distinct pipelines, giving an increased annual production of 34 million kWh. There was also an instance where two small independent plants were installed, giving a production of 31 million kWh a year.

Two modifications each utilising the existing head loss between a canal and the level from which this canal is derived, have given an increased production of 25 million kWh per annum.

Finally, an underground reservoir, with a capacity of 16 million cubic metres of water, at the head level of the plants on the River Aude will augment their production by about 30 million kWh and improve their operating characteristics.

The diverse categories of works mentioned above amount in all to an economy of more than 100 men in hydro-electric stations, and to a supplementary production of about 450 million kWh per annum by the aid of renovated plant. One can thus justly say that in the hydraulic field " From little streams great rivers grow."

The Avimo Borehole Camera

AN interesting advance of borehole surveying is announced by the Avimo Research Laboratory, who claim that many of the problems arising from attempts to photograph the full interior surface of a borehole have now been solved by them. As a result they have designed a camera said to be capable of taking such photographs with a high degree of accuracy. Each photograph gives a complete picture of the full circular section at the point chosen, and we understand that even slight faults can be detected and their position accurately determined.

By the use of this camera it is possible, we are told, for a complete photographic record of any bore to be made extending from the surface to a depth of as much as two miles, provided the hole is empty or contains only transparent liquid or gas. The portion of the borehole under consideration is photographed directly on to a film from which an exact reproduction of the complete circular interior surface is afterwards projected and printed. As the camera is lowered successive photographs are automatically taken, so that, when integrated, a complete full-size record is obtained.

The camera and its ancillary equipment is housed in a steel cylinder divided into seven compartments. The first, which forms the nose, houses bellows for the equalization of pressure, while the second contains the window and reflector through which the entire walls of the borehole are photographed. Adjacent to this is the lamp chamber and the camera, behind which are situated the film magazine, then follows the electronic control section and finally the gland compartment.

The cable which supports the cylinder housing also carries the current and certain electrical control impulses, and is led to a surface-winch, on which is mounted the electronic control-gear for the precise lowering of the " shell " and the synchronising of the illumination and film exposure at predetermined sequences.

The dimensions of the housing are such that the device can operate in boreholes of as little as five inches in diameter. Further research is still proceeding and we look forward to hearing of the application of this useful instrument in many types of drilling.

Robinson & Kershaw Limited.—A £100,000 order for structural steelwork — the third within eight months—has been received for a large hydro-electric project in Tasmania. With the two earlier orders, both for about the same amount, it will mean two years' production work at the Dukinfield factory of Robinson & Kershaw Limited, structural engineers. Steelwork exported by the firm will go to the building of 80 ft. towers and hydro-electric plant in a scheme covering the whole of Tasmania. To cope with these and other orders and resulting expansion, the entire factory of Robinson & Kershaw was moved from Manchester to a former railway works in Globe Lane, Dukinfield, earlier this year.

A second edition of the ***Electrical Engineers' Compan.on*** has just been published by the London Electric Wire Company and Smiths, Limited, 24 Queen Anne's Gate, Westminster, S.W.1 (price 5s.). While the pocket size of the book has been retained, its contents have been brought up to date and arranged and indexed for speedy reference to any specific subject. Rarely have so many facts and formulae been assembled in so small a volume.

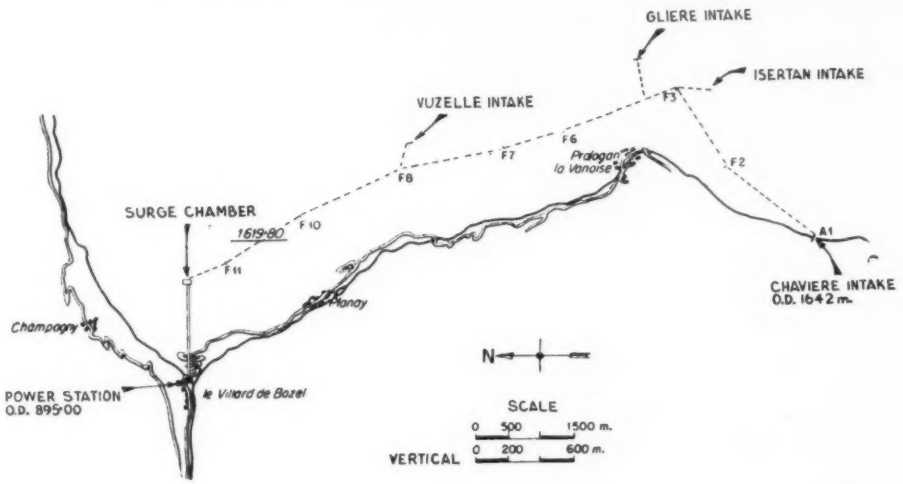
From the Journals of the technical institutions and other material published in the Press of the World

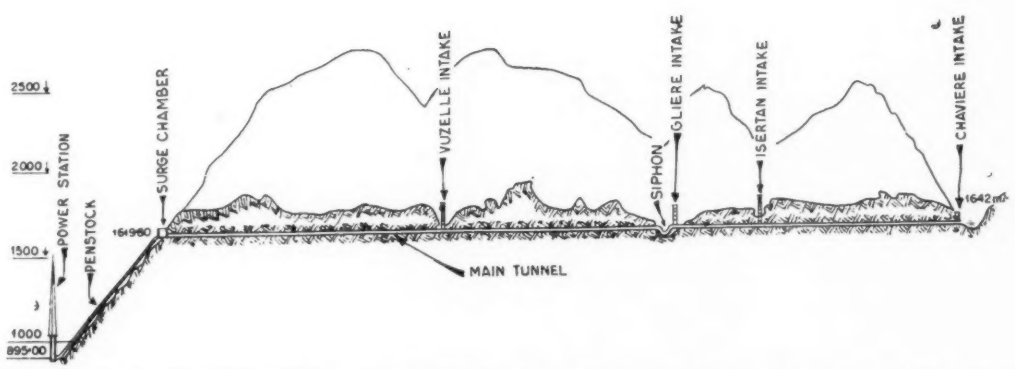
The Penstock of the Pralognan Falls

The Pralognan basin lies above Moutiers, on the left bank of the Isère, below the great Vanoise massif. In spite of very favourable conditions this area has not been tapped to the same extent as its neighbour, the Beaufortine, which has now eight power plants in operation. There is still room for further development on a large scale and, in consideration of the industrial character of this region, Electricité de France, the French equivalent of our Electricity Authority, have set up the new Pralognan plant which is designed for a flow of about 282.5 cu. ft. per second under a head of 2,378 ft., and equipped with three 17,000 kVA alternators driven by 22,000 h.p. horizontal-shaft Pelton turbines running at 750 r.p.m.

The original project worked out by a private concern has been considerably extended by Electricité de France, and the capacity of the powerhouse built at the confluence of the Doron de Champagny and Doron de Bozel has been increased to 170 M. kWh p.a. This article deals mainly with the penstock of the new plant.

From the beginning of the preliminary surveys, in 1943, and owing to the scarcity of steel, it appeared necessary to use for this penstock light welded pipes





so as to reduce the consumption of steel to the lowest possible limit. Finally the penstock was divided into three sections, each with the following main characteristics:—

TOP SECTION: about 463 ft. in length, laid at an elevation of between 5,311 and 4,938 ft., consisting of welded pipes 1,450 mm. in diam., made of plates 6 to 7 mm. thick;

MIDDLE SECTION: about 2,579 ft. in length, elevation 4,948 to 4,078 ft., consisting of steel pipes 1,450 mm. in

diam., 6 to 11 mm. thick, reinforced by stranded steel ropes coiled at a pitch of 55 to 70 mm;

BOTTOM SECTION: about 2,235 ft. in length, elevation between 4,078 and 2,943 ft., consisting of steel pipes 1,300 mm. in diam., 9 to 25 mm. thick, reinforced by rigid steel hoops 60 to 70 mm apart.

The aggregate weight of the penstock is about 1,180 tons.

An interesting feature of this scheme is the fact that the power house is built exactly on the path followed by the penstock of the Villard plant, which is still in operation. Actually this penstock runs through the basement of Pralognan powerhouse; as it was laid as early as 1911, and does not satisfy the present regulations, it was thought safe to reinforce it by means of pairs of parallel steel slings made of lengths of steel rope connected by loops at each end, and fitted with tightening clamps.

This article emphasises the difficult conditions under which this job had to be carried out, and ends with interesting details about the transport of materials, and the assembling of the pipes on site. The penstock was tested under working conditions in June 1949, and the plant put into service three months later. *(M. H. Beaumel, "La Houille Blanche," Vol. 5, No. 2, p. 131, 13 pp., 14 ff.)*

Improvements in Measuring Tanks

As a discharge measuring device the measuring tank has definite advantages over other methods, such as those using weirs, venturi flumes or current meters, as it obtains more accurate and more reliable results. It gives, indeed, the direct measurement of a known volume with a high degree of accuracy, and is, in addition, practically the only medium which can be used for checking measurements obtained by other methods. On the other hand its main drawback lies in the length of time required by the stabilisation of the water level after filling and emptying, and this often causes considerable delays.

Tests carried out at the Neyrpic Laboratory have paved the way to improvements through which the measuring tank is now as quick a measuring apparatus as any other known device, without losing anything in accuracy and reliability. This has been achieved by improving, in the first place, the water supply system in such a way that a cone-shaped pipe, acting as a baffle, delivers the water in the middle of the tank and close to its bottom, so as to avoid sudden fluctuations of level as well as clapotis. Differences of level may, however, occur between the cone-shaped pipe and the tank proper in case of discharge fluctuations, and this may cause a considerable amount of air to be carried into the tank. To remedy this and ensure a quick stabilisation of the water level in the tank, the cone-shaped pipe is connected at its top with a spiral casing *1* as shown in Fig. 1. The cone-shaped pipe *2* rests on a ring *3* fitted with radial ribs *4* which act as supports and, at the same time, prevents the water from entering the tank with a rotary motion. The water leaving the spiral casing flows closely along the wall of the cone-shaped pipe and takes the shape of a hollow cone which revolves at a very high speed, so that the air carried along escapes freely through the round hole *5* provided at the top of the casing. By means of a guiding vane fitted in the casing the flow can be roughly regulated so as to reach its maximum for any given discharge. This arrangement enables the water supply to be perfectly free from air. The dissipation of energy is further increased by panels of grating fitted around the bottom ring. The whole device has proved highly satisfactory, and enables reliable readings of the water level to be taken within a few minutes of the discharge being cut off.

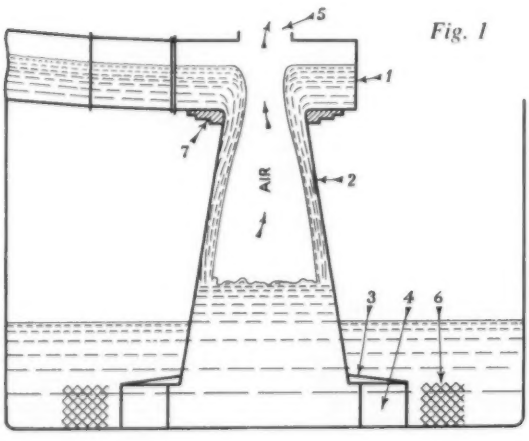


Fig. 1

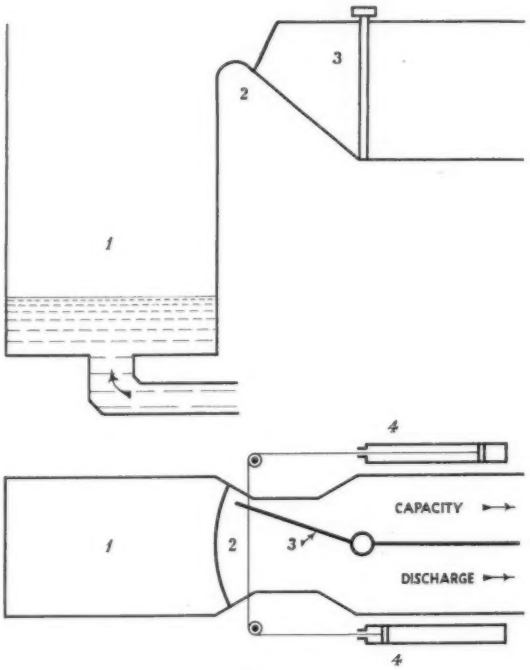


Fig. 2

After a certain number of readings the water in the tank rises to such an extent that it becomes necessary to drain it; this must, however, be done in such a way that the surface of the water is not disturbed, and measurements may proceed without too long an interruption, while leakage of water through the

draining arrangement is avoided. This double problem was solved by a siphon-draining system; three vertical siphons fitted through one of the walls of the tank, draw off the water from three rectangular troughs

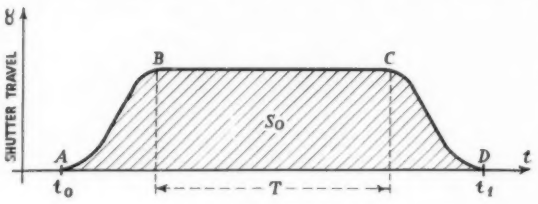


Fig. 3

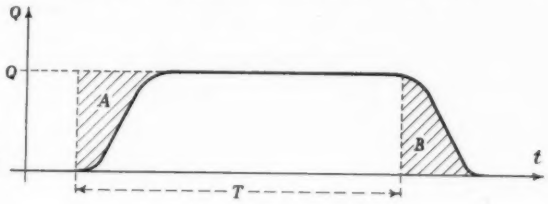


Fig. 4

placed at the bottom of the tank; these troughs are covered by sheets of "Eternit," an asbestos compound, provided with openings which increase in size with their distance from the suction point of the siphons. This permits a constant discharge through all the openings, and avoids level fluctuations which might occur while draining is in progress or at the moment priming stops, when the water in the siphons flows back into the tank.

Priming can be effected by means of a vacuum pump but takes place automatically as soon as the water reaches the priming level of the siphons; this priming level is below the maximum level of the water, so that overflowing through faulty handling cannot occur. Emptying can be interrupted at any required level by opening air-inlets fitted in the siphons. Another major advantage of the siphon-draining system is the absence of leakages of water which can hardly be avoided in other systems, such as valves fitted in the bottom of the tank.

As shown in Fig. 2 the apparatus includes a feeding tank *1* which collects the discharge to be measured and delivers it to the measuring tank over a sill *2* which produces a torrential flow. A servo-motor-controlled vane enables the flow to be directed towards either the measuring tank or an escape channel; this vane is fitted with a water-tight rubber joint which prevents leakage at the end of its travel. The possibility of creating a torrential flow on a short distance prevents flow conditions downstream from having any repercussion upstream on the discharge to be measured.

The filling time is ascertained by means of a meter fitted with two recording pens, one being connected to a high-precision chronometer which registers a spot every second, and the other to the flow divider, so as to record the angle of rotation α of the vane.

Fig. 3 shows an example of the time-travel curve $\alpha(t)$ corresponding to the reading of a discharge: section *AB* represents the beginning, and *CD* the end of the discharge, while *BC* is the filling period of the measuring tank. A time-discharge curve is shown in Fig. 4, in which areas *A* and *B* are equal. The water flows therefore at a constant rate of discharge *Q* during the time *T* which elapses between the opening and subsequent closing of the vane. The discharge is therefore expressed by

$$Q = \frac{V}{T},$$

in which *V* is the volume measured in the tank. Levels are measured by means of a cathodic-eye measuring point which gives measurements with a maximum absolute margin of error of 0.1 mm.

The initial gauging of the measuring tank is done by means of a graded vessel with a capacity of about 66 gallons, the volume being determined within 1/10,000 by weighing. Gauging itself is effected by emptying the graded vessel several times into the measuring tank, and recording the corresponding levels. The arrangement used at the Neyrpic Laboratory can cope with a maximum discharge of 10.6 cu. secs., and it is claimed that measurements can be made with a margin of error of no more than about 0.1 per cent. *(Article contributed by the "Laboratoire Dauphinois d'Hydraulique," Grenoble, France, to "La Houille Blanche," Vol. 5, No. 3, May-June 1950, 7 pp., 11 ff.)*

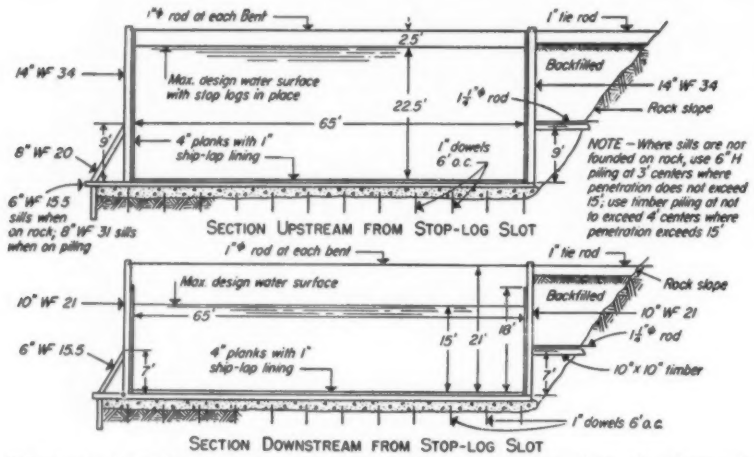
Missouri Diversion at Canyon Ferry

The worst hazard to be tackled in the construction of the relatively small dam at Canyon Ferry rests in the diversion of the Missouri River through this flood season and next. The 212 ft. high, 470,000 cu. yard dam, now in its first construction stage, with excavating under way and concreting ready to start, is located 17 miles northeast of Helena, Montana; the project is planned to control flows exceeding at times 30,000 cfs, supply irrigation water to 310,000 acres, permit production of 50,000 kW by three units, and regulate discharge for six downstream plants of the Montana Power Co.

River diversion was complicated by both the design of the dam and the physical features of the canyon. The dam is to have a centre overflow spillway that will occupy the original riverbed from the sheer rock of the left abutment to a point near the right bank. There appeared to be not enough room in the canyon for open channel diversion if the spillway were to be built in one construction stage while, on the other hand, a tunnel or tunnels of sufficient flow capacity would have proved a slow and costly process in the hard and brittle abutment rock.

The contractor turned the difficulty by building a 65 ft. wide flume extending 1,000 ft. along the right bank; moreover, to strike a balance between the cost of a larger diversion and the possible cost of damage in case of the diversion structure being overtopped, he chose 23,000 cfs as the design flood, despite the fact that flow exceeds that rate at an average of one year out of five. By crowding the freeboard of the flume 25,000 cfs might be accommodated, but that is still far below the 34,000 cfs record discharge of June, 1948. If flows in excess of capacity occur, the contractor plans to dig a channel around the left end of the upstream cofferdam; this would mean flooding the excavation but should, at least, save the cofferdam.

With its floor level at the normal river surface elevation, the flume is—for most of its length—on a bench in the rock abutment, and is supported throughout its length by steel sills spaced on 6 ft. centres. Where they are on the rock, these sills—6 WF 15.5 lb. beam sections — have been embedded in concrete anchored to rock with 1 in. dowels set on 6 ft. centres; they had 1 in. rods spot-welded to them, like legs, for support while the concrete foundation was poured.



Missouri diversion flume; upstream from the stop-log slots the flume is designed for the greater depths it must hold during the changeover to the second stage

Where sills could not be founded directly on rock, piles were driven, and 8 WF 21 lb. steel sections were used. Where penetration exceeded 15 ft., timber piling was used with a maximum of 4 ft. between piles; with penetration under 15 ft., 6 in. steel H-piles were driven on 3 ft. centres. Flume walls and flooring consist of 4 × 10 and 4 × 12 in. planks grooved on both edges and joined together with 1 × 1½ in. splines. Over the planking is placed a layer of roll roofing material, and 1 in. ship-lap is nailed over that.

About 61 ft. downstream from the intake of the flume, stop-log slots are built into the side walls, and a recess with a removable cover is built into the floor; the vertical slots are 2 ft. 7 in. wide and 13 in. deep, running the full height of the wall. They will hold 67 × 3 ft. stop-logs built to close off flow through the flume. The covered recess in the floor is to have a vertical beam section inserted in it to back up the stop-logs when they are used. The inlet transition section of the flume is constructed of interlocking steel sheetpiling driven to rock. Both inlet and outlet ends of the flume are protected by steel sheetpiling cutoff walls; they are capped with concrete blocks to which the first few sills are bolted. The downstream end of the flume is further protected by heavy riprap. The upstream and downstream cofferdams are interlocking sheetpiling, driven to rock and backfilled with sand and gravel from the river bottom.

An unusual item of equipment used in excavating the foundation area and constructing the cofferdams was a floating gold dredge from which the gold recovery attachment had been disconnected, the excavated material passing directly from the digging ladder to the conveyor in the stacker. Before sheetpiling was driven for the cofferdams, the dredge was used to dig a trench across the river along the line of each cofferdam; the larger material from this excavation was stockpiled for later use as backfill while as much as possible of the finer material was permitted to flow back into the bottom of the trench. This formed a solid support through which the piling was easily driven to rock.

Openings were left in both cofferdams to pass the river until final closure was effected. Before the actual diversion, Montana Power Co. had released most of the water from Lake Sewell behind the old Canyon Ferry Dam, just above the new dam site to make storage space available. When the diversion was made there was enough capacity available in the old reservoir to close off the river and store all its natural flow for 12 hours, while the cofferdam closure was effected.

Use of the flume presents an ideal opportunity to study flow characteristics in a full-size structure. Staff gauges are installed in pairs on its walls throughout the length of the flume, and a programme is set up for reading the gauges at various discharge volumes.

When the contractor began pumping down the area between the cofferdams, early in the spring, inflow from leakage was high. A dumped clay blanket was, therefore, placed over the outer faces of both cofferdams, and the installed pumping capacity was increased; this resulted in drawing the clay into the pervious material of the cofferdams, sealing it to a large extent against leakage. It is, however, estimated that there is still a leakage of about 8,000 to 10,000 gal. p.m., and concrete cutoff walls have been built to intercept leakage and lead it to sumps from which it is being pumped into the flume.

After the left abutment foundation has been grouted, concreting will begin. This portion of the dam will have four 84 in. permanent river outlet conduits and, in addition, the contractor will be permitted to construct two 10 ft. dia. temporary river diversion tubes through the diam. Also, low blocks will be left for carrying high flows during second stage diversion.

Changeover from the first to second stage diversion will involve placing the stop-log gate structure in the diversion flume, and diverting the river through the river outlet conduits. Auxiliary cofferdam structures will then be constructed at the upper and lower ends of the flume, so that the flume can be removed.

By means of a 1,400 ft. cableway spanning the canyon (the crest length of the dam will be 1,000 ft.) the contractor will be able to place directly all the concrete in both the dam and the powerhouse; some of the material will, however, have to be rehandled for the downstream part of the spillway apron. *(William P. Price, Jr., "Engineering News-Record," Vol. 145, No. 5, August 3, 1950.)*

GLENFIELD

CONTROL VALVES

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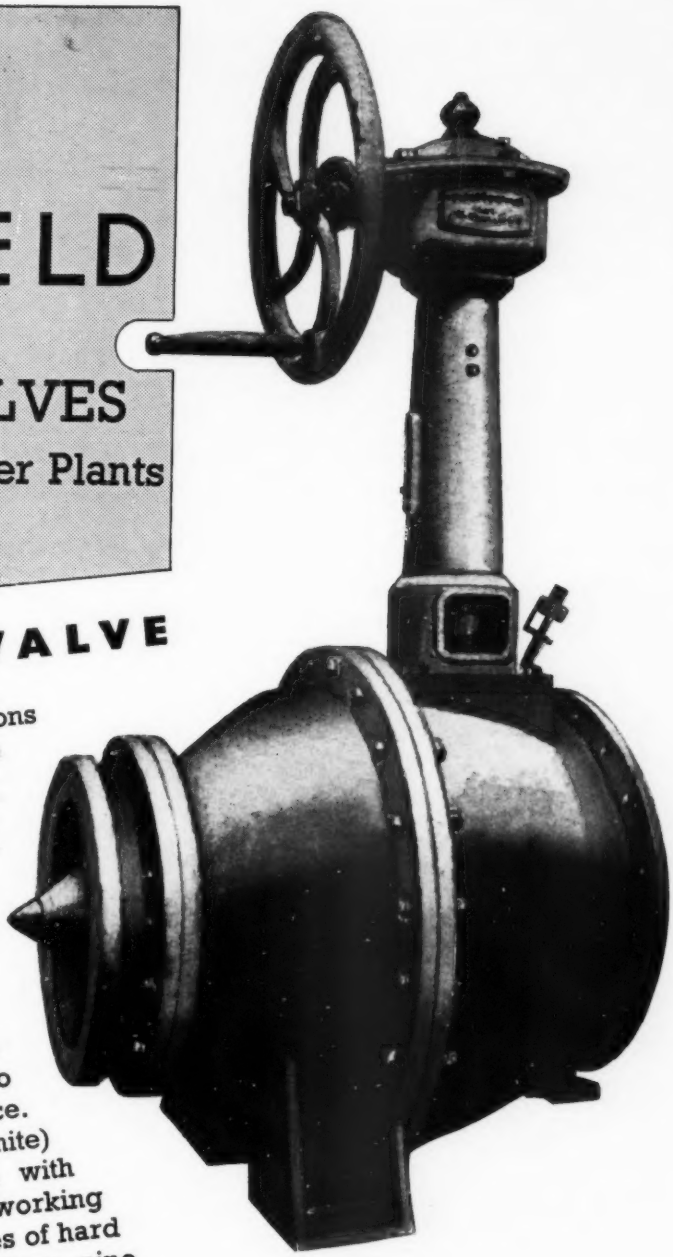

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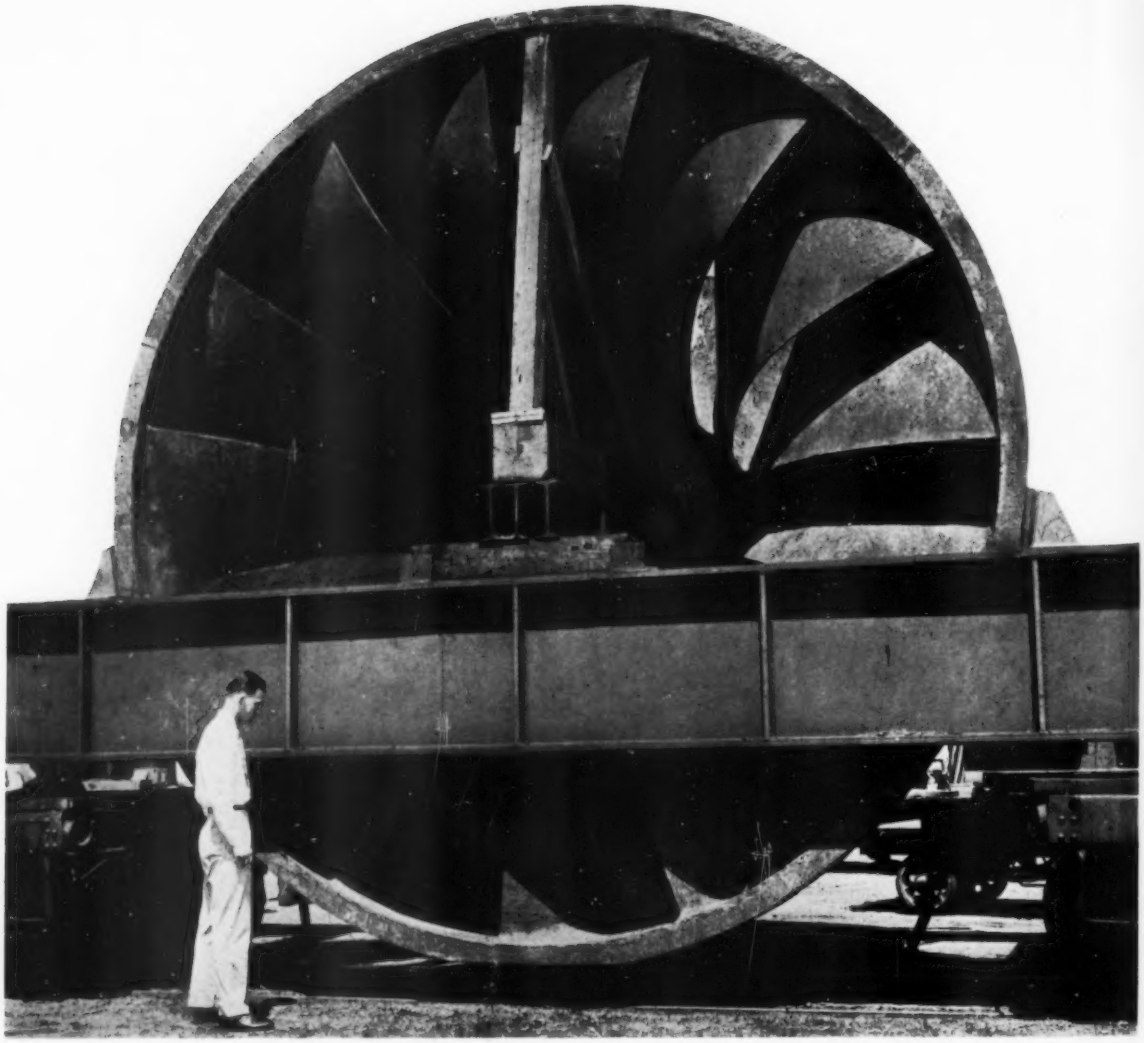

FACILITIES FOR THE SMALLEST OR LARGEST

The 225-acre Newport News plant includes plate steel and machine shops equipped with a complete variety of tools to fabricate items of water power equipment of any size. Contracts received by Newport News for hydraulic turbines with an aggregate rated output in excess of 7,000,000 horsepower have included units as high as 165,000 horsepower and as low as 500 horsepower.

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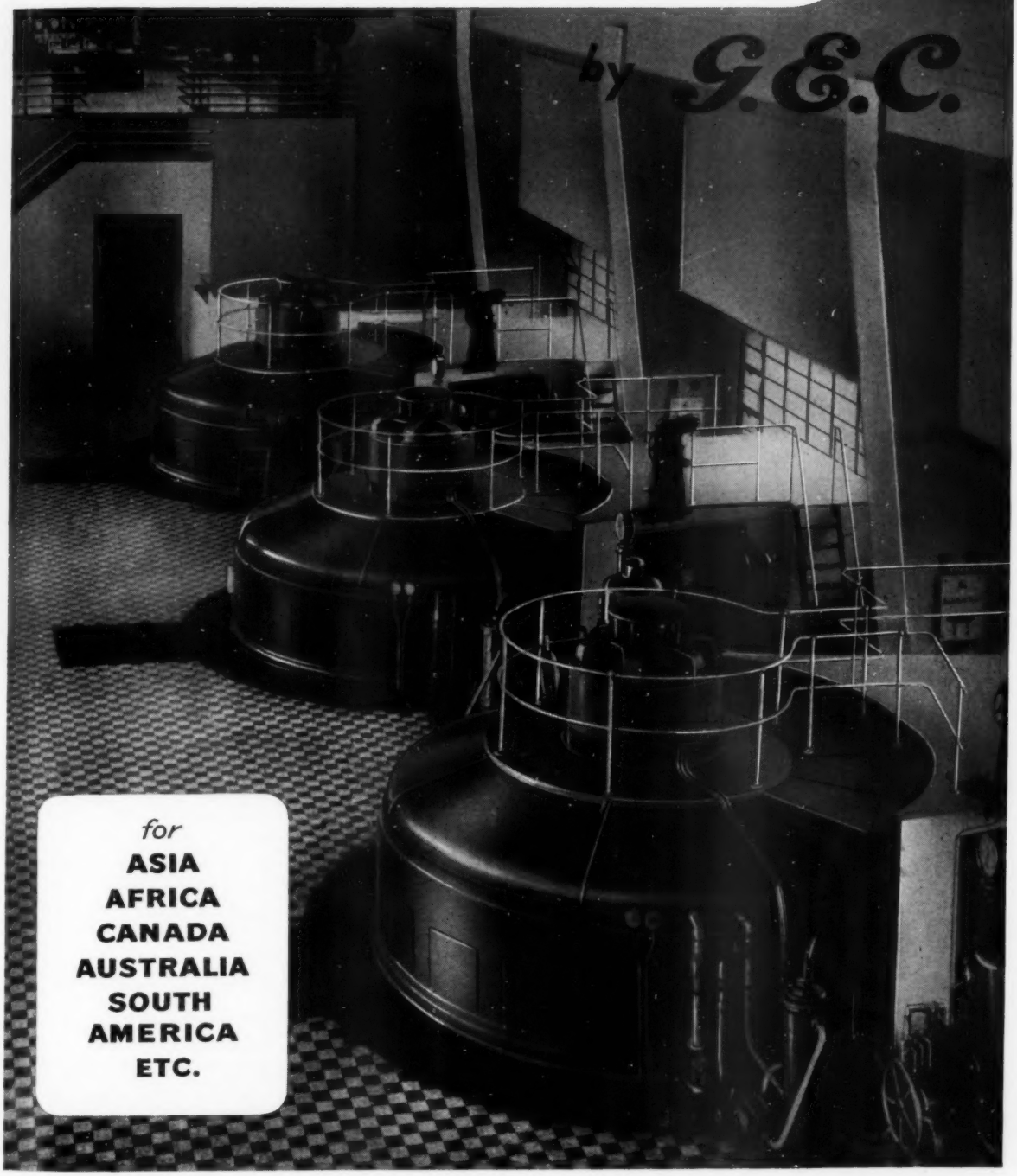
HYDRO - ELECTRIC PLANT

by G.E.C.



for
ASIA
AFRICA
CANADA
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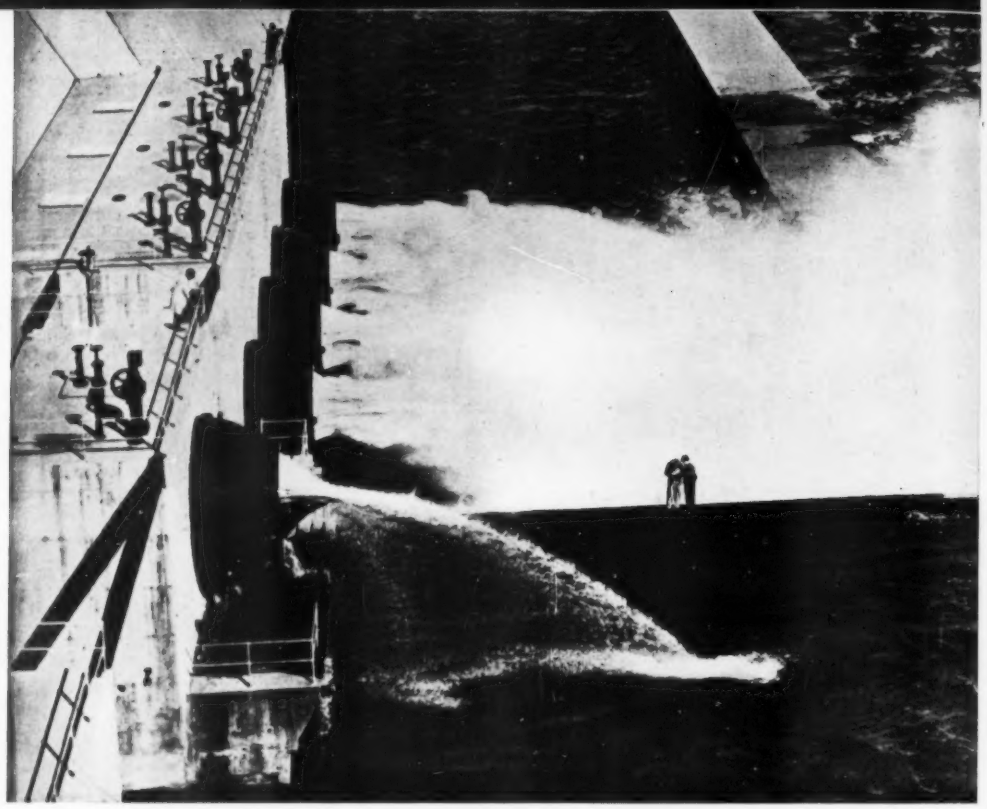
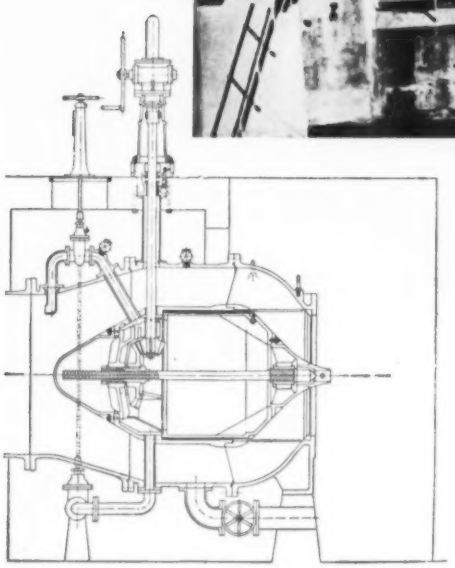
SOUTH AMERICA
ETC.

DISCHARGE REGULATORS FOR DAM OUTLETS

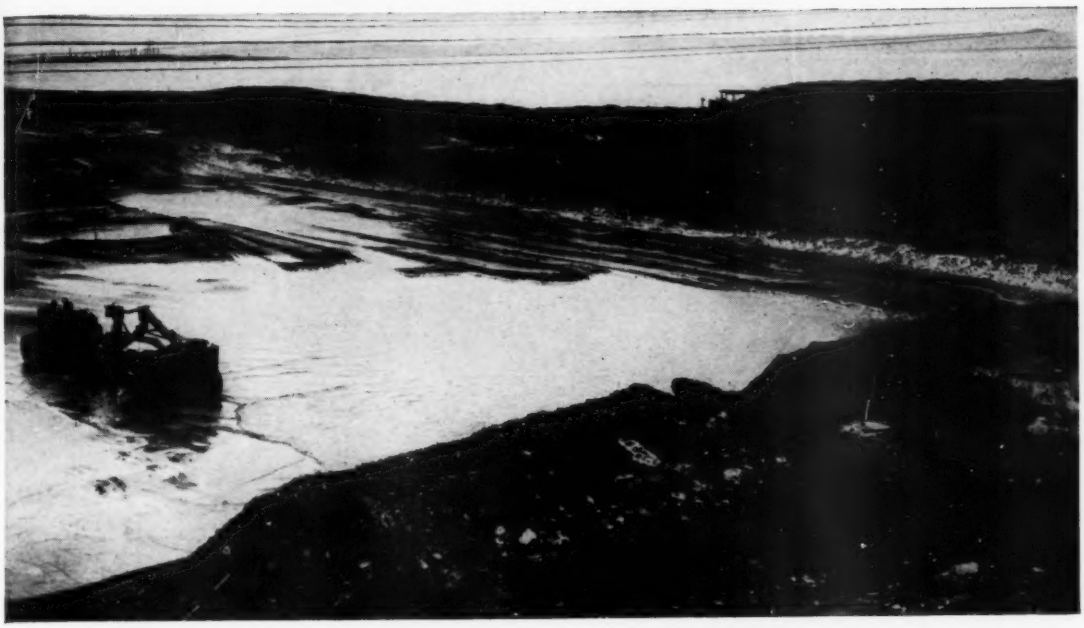




The Larner-Johnson valve possesses exceptional qualities for free discharge control. No other valve provides so complete an answer to the dual problems of high velocity flow and hydraulic unbalance associated with this duty. Being of true streamline form, it passes a smooth jet at all openings, giving freedom from vibration and erosion under the highest heads. Operation is by means of the pipe line pressure acting on the plunger, governed by an internal pilot valve control which holds the plunger in balance at all open positions (when stationary) and creates the appropriate unbalance for opening or closing. Ease of operation is thus ensured, irrespective of size or pressure. Simplicity of design, freedom from distortion troubles, absence of sliding surfaces under pressure, all contribute to the success of the valve over the full range of conditions. Some of the largest valves of their class are of Larner-Johnson type, amongst them the three 13 ft. by 7 ft. 6 in. and four 9 ft. by 7 ft. 6 in. regulators at Hume Dam, on the Murray River, Australia, certain of which appear in the adjoining photographic view.

Full particulars from : **J. Blakeborough & Sons Ltd.,** Brighouse, England.

BLAKEBOROUGH



A RECORD WELLPOINT CONTRACT

This site, the largest ever excavated in Great Britain with the use of the Wellpoint Dewatering System, is an excavation for the foundation of the British Electricity Authority's Carmarthen Bay Generating Station, situated at Burry Port. The consulting Engineers and Contractors are Messrs. Balfour, Beatty & Co. Ltd. The permanent water table is 8ft. below ground level. The Turbine Room excavation alone, measuring 350 ft. x 250 ft. was dewatered to a maximum depth of 36 ft. within 100 ft. of the sea at high tide. A further extension of similar size is now being undertaken.

The upper photograph shows excavation of permanent water level 8 ft. below the surface.

Below is illustrated a portion of excavation to 36 ft. deep in sand, without timber or other supporting work.

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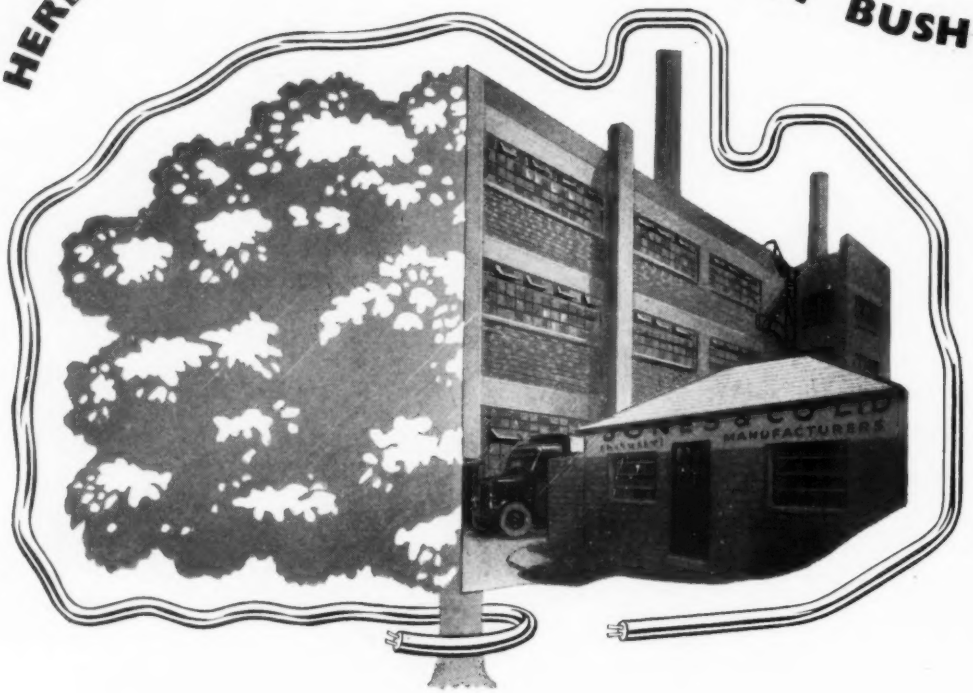

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The harnessing of Loch Fannich...

The Loch Fannich project in Ross-shire, Scotland, is part of the North of Scotland Hydro-electric Board's plan to provide hydro-electric power to feed a 132,000 volt grid serving Northern Scotland.

The power station at Grudie Bridge will house two 13,333 kVA Francis turbo-generators directly connected to two 20,000 kVA transformers.

13,333 kVA. 11,000 volt, 500 rpm. vertical generator for the Loch Fannich scheme.

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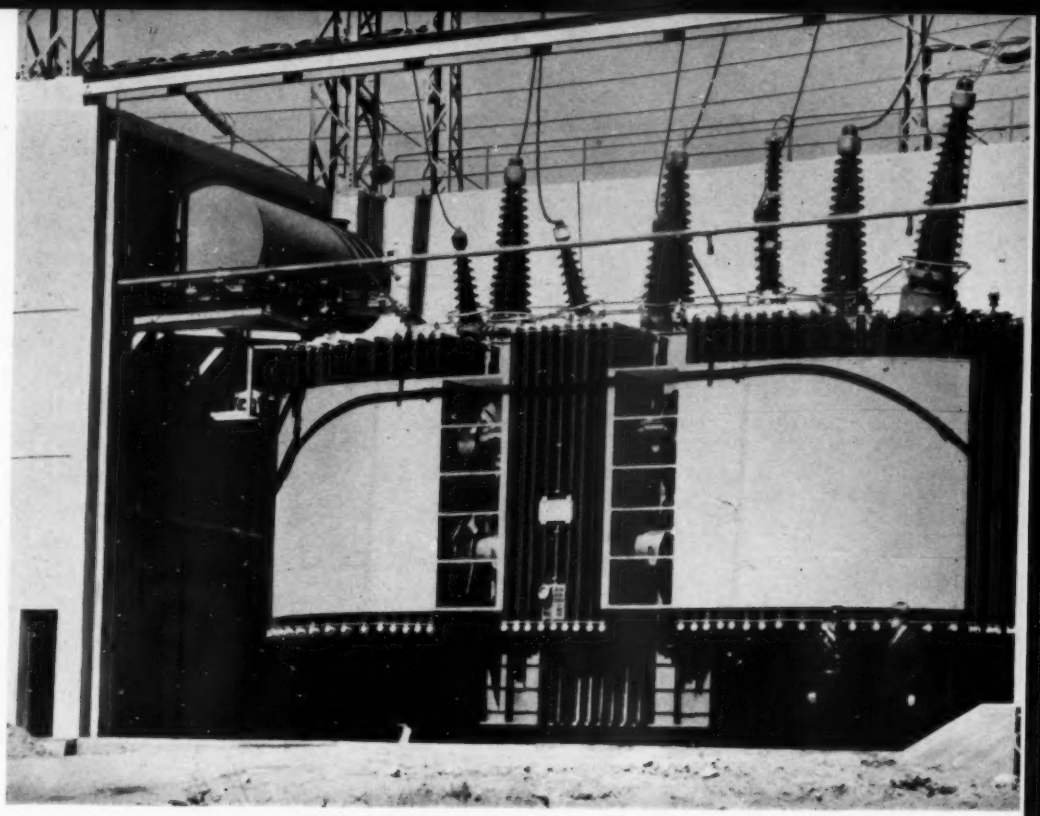

125,000 kVA three-phase transformer, probably the largest ever manufactured. Provided with four separate windings rated at 125/60/125/15 MVA, 200/100/36/6.6 kV, 50 p/s.

A Record in Transformer Construction

The majority of power plants in Sweden are situated in the northern part of the country where water power is abundant, whereas the big power consuming districts are located in central and southern Sweden. Power must therefore be transmitted over very long distances, 300 miles or more, which necessitates the use of a high transmission voltage.

Since 1937 the standard transmission voltage has been 220 kV and, in all, 73 Asea transformers for this voltage are now in service, covering a total output not far short of 3,500,000 kVA and ranging from 3,000 to 125,000 kVA units. Five of these units are rated at 120,000 kVA or more. A further 33 transformer units designed to operate on 220 and 275 kV with ratings up to 135,000 kVA are in course of construction for customers in Sweden and other countries. It should be noted that practically all these transformers are built as *complete three-phase units.*

The method of banking three single-phase transformers will be resorted to in the next stage of transmission development in Sweden, *the 380 kV system,* for which 18 transformers are now being built, with single-phase ratings up to 115,000 kVA, *i.e.* 345,000 kVA per three-phase bank.

These figures give ample evidence of Asea's transformer manufacturing capacity and the experience and technical knowledge which are at your disposal.

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Engineer and Manager—Alan Atkinson, Esq., M.Eng., M.I.C.E., M.Inst.W.E.

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This tunnel, ten miles long, forms the middle section of the aqueduct which when completed will bring water from Haweswater in the Lake District to Manchester. The conditions for tunnelling under the Bowland Hills are difficult, varying from soft mudstones to sandstones containing water at high pressure, such as in the heading shown above from which over two million gallons of water are being pumped each day. Despite these varying and difficult conditions, a progress of 236 feet has been obtained in one week in ground requiring continuous steel arch support right up to the face.

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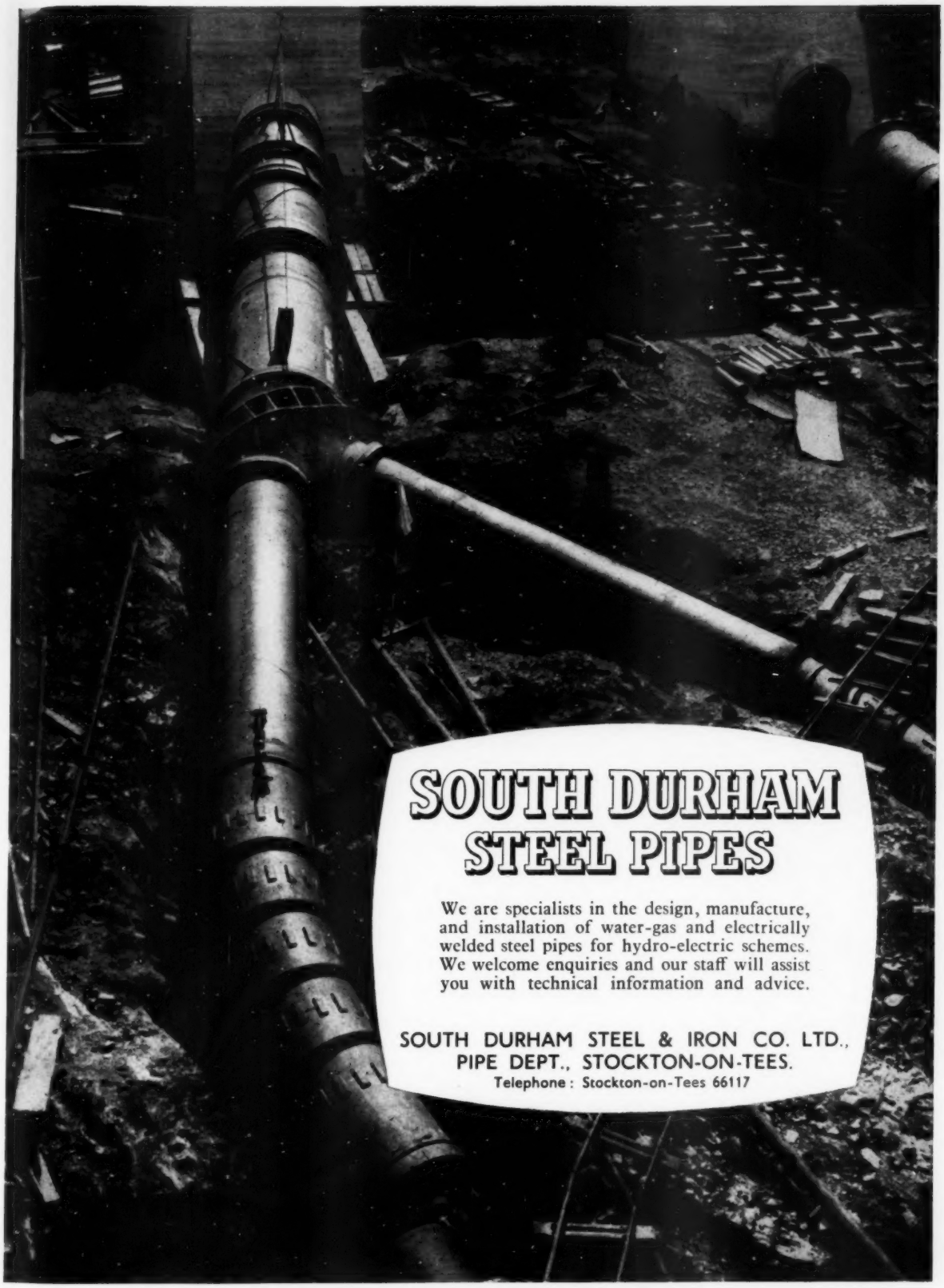
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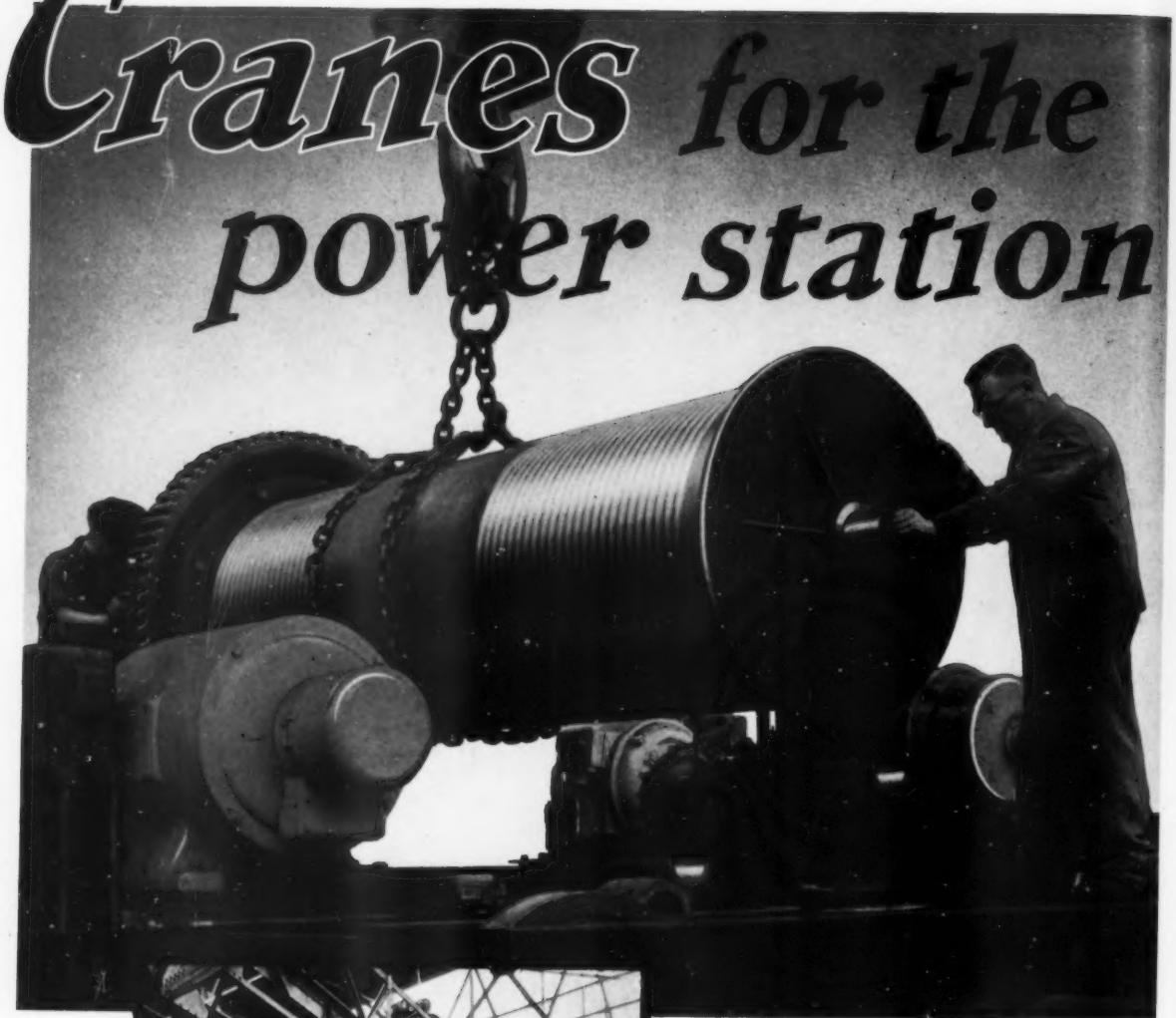
Cranes for the power station



THE massive rope drum for a 110-ton Morris crane is here shown being lowered on to the crab frame. Behind the drum is the crab traversing gear and the auxiliary lifting gear which in this instance is for a capacity of 10 tons. The crane was recently despatched to a hydro-electric power station in India —one more to the long list of Morris cranes already giving reliable service in power stations all over the world.

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Henderson Cranes are chosen so often because of their speed and versatility in lifting materials. Their safety and economy in operation are also assured. Supplied to many leading contractors Henderson Derrick Cranes of all types and capacities can be manufactured for steam, electric, petrol or diesel drive. Cranes can also be fixed or travelling types. Normal sizes are from 10 cwt. to 60 tons Load capacity. With jibs up to 120 feet.

View of Henderson Cableways during the construction of the Claerwen Dam, courtesy of the Birmingham Corporation Water Works. Contractors Messrs. Edmund Nuttall Sons & Co., Ltd.

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SPEED? The Holman Rotofeed Drifter reduces overall drilling time. Its lightweight air motor gives a constant penetration speed equal to the maximum a hand feed drifter can produce while the speed of retraction is very much faster. If tungsten carbide tipped Holbits are used this drifter will regularly drill holes of 10-12 feet with **only two steels.**

ECONOMY? The Holman Rotofeed Drifter cuts out the manual labour of drilling, and in fact demands very little attention from the operator. The economy of this is obvious. Like all Holman machines, this drifter is designed and constructed for a long life—and a hard one.

EASY HANDLING? This is an unusually lightweight drifter. Its aluminium alloy (Holmaloy) cradle is 50 per cent. lighter than the steel type, the weight varying according to the type of chuck and cradle used. To control the machine is simplicity itself: a single handle regulates both direction and rate of feed.

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Type	*Bore*	*Weight*	
SL.200... ...	2¼ ins.	114 lb.	Very light weight for medium work.
Silver Bullet	2⅝ ins.	124 lb.	Light weight for medium work.
SL.240... ...	3 ins.	153 lb.	Medium weight for general purpose work.
SL.250... ...	3⅛ ins.	165 lb.	Medium to Heavy Duty.
SL.280... ...	3½ ins.	180 lb.	Heavy Duty Drifter.

These machines also available as Handfeed Drifters.
Vented and Non-vented Models Supplied.
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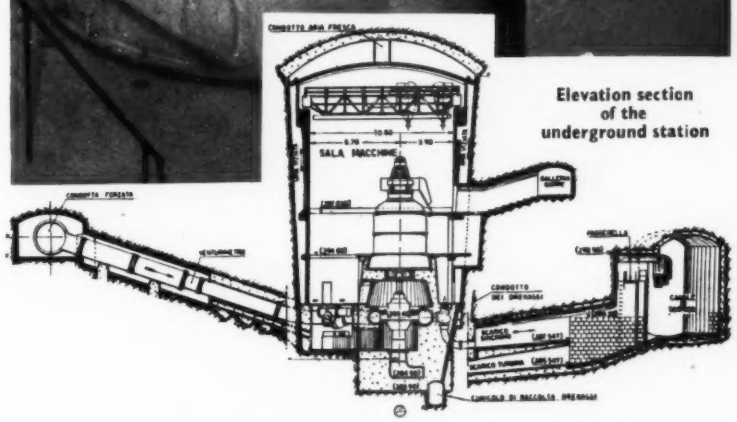

Elevation section of the underground station

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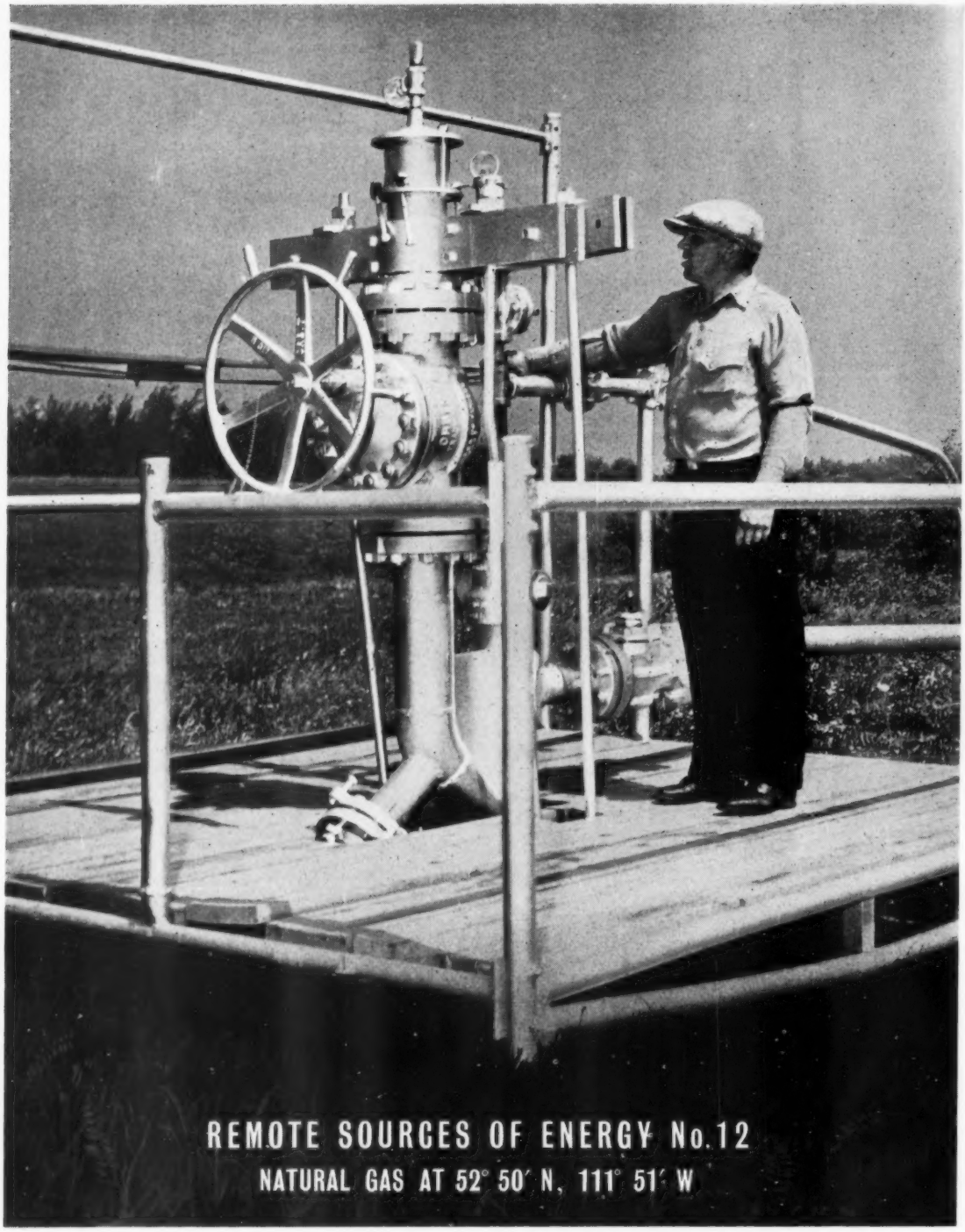

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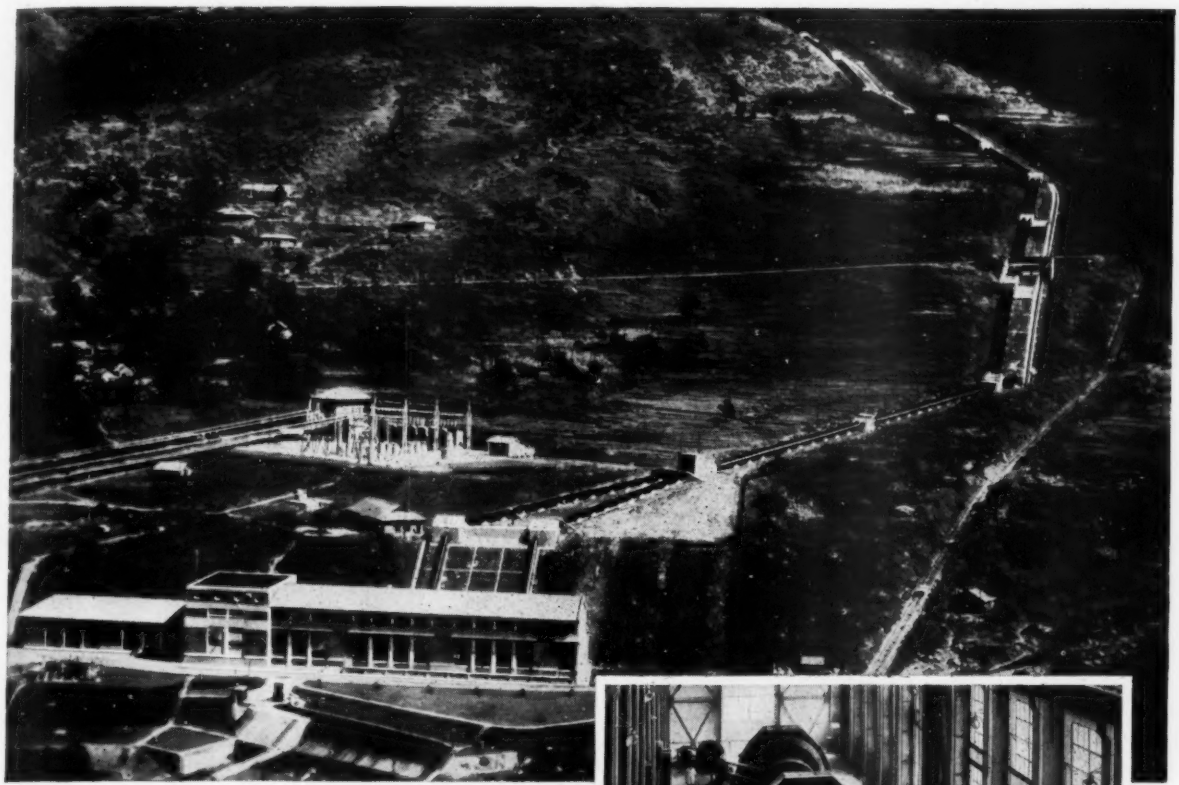

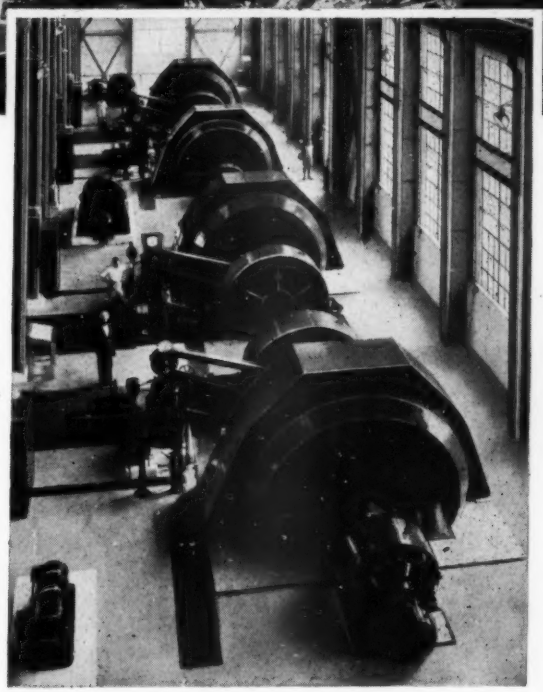

General view of Shanan Power Station

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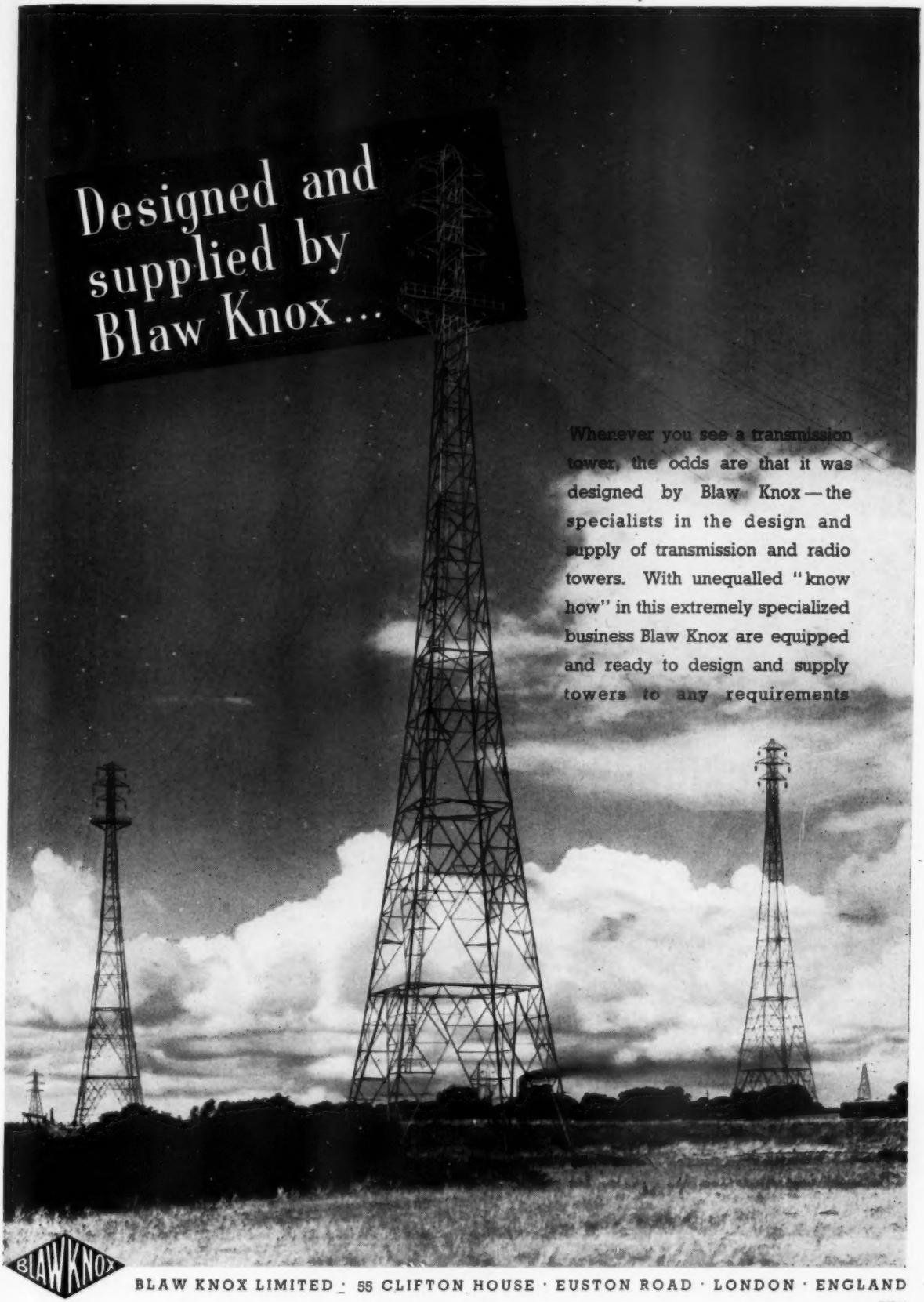
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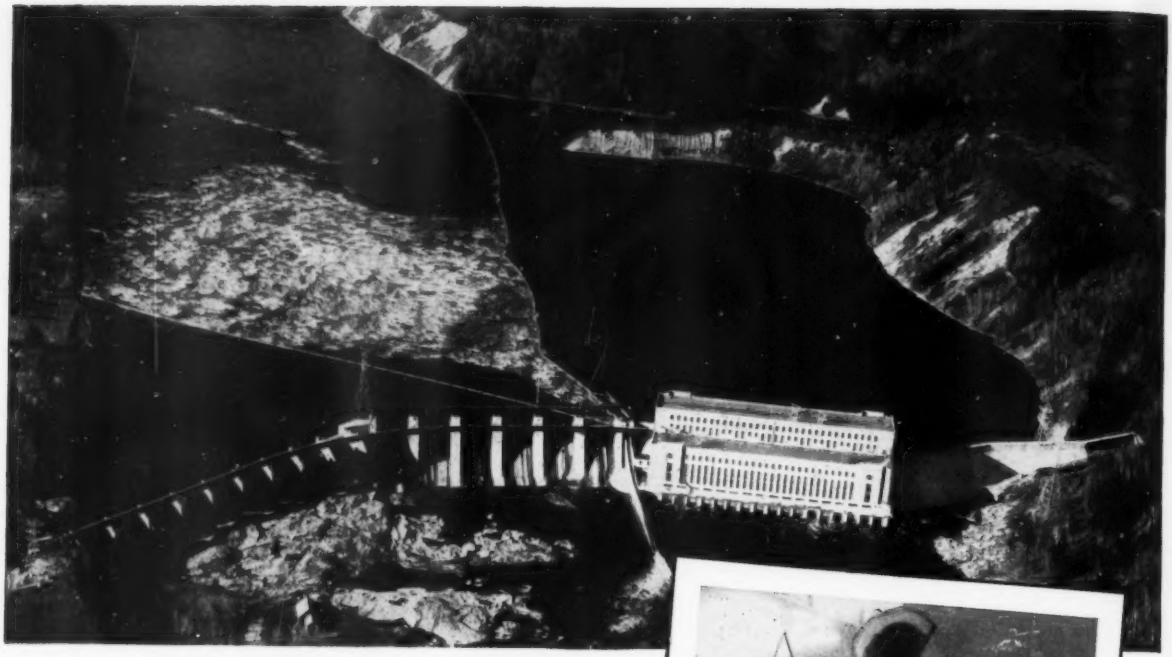
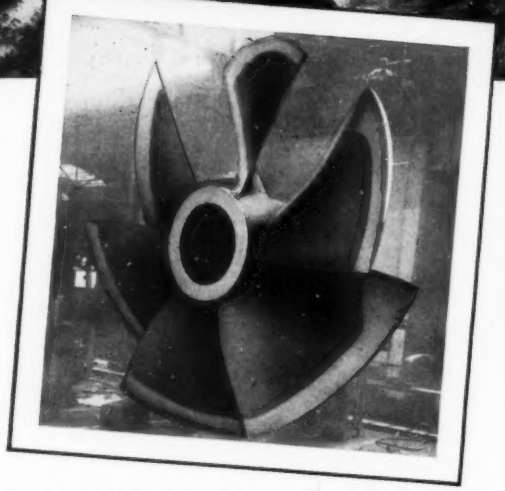


The La Gabelle plant of the Shawinigan Water and Power Company, containing five Dominion fixed blade propeller turbines of 35,000 H.P. each, at 120 R.P.M. under a head of 60 feet.



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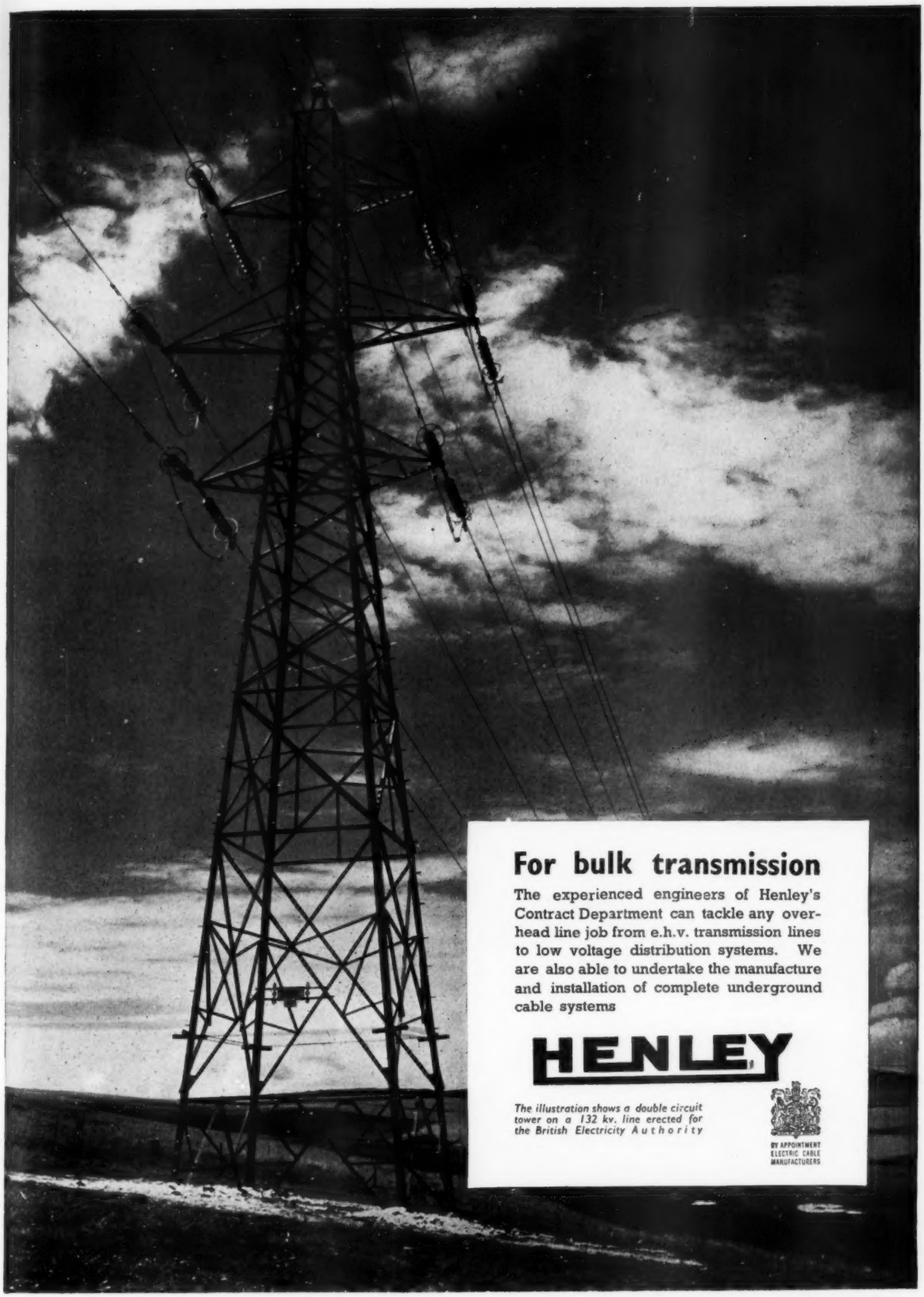
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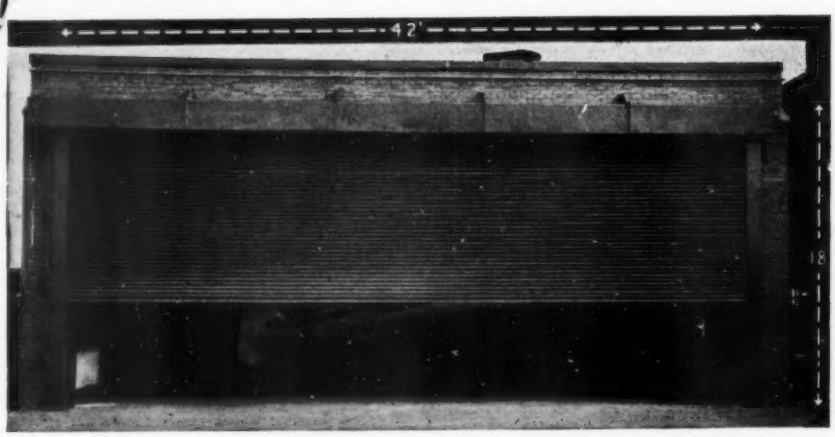

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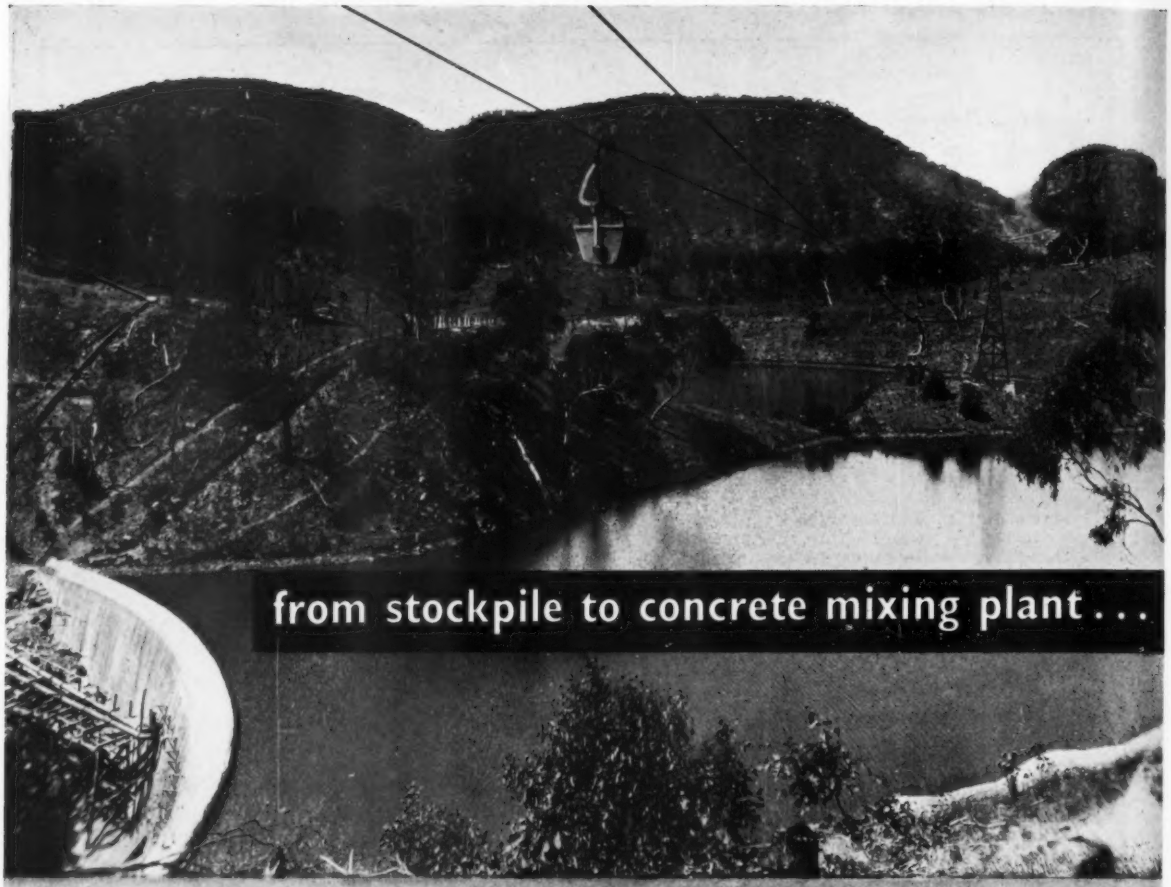

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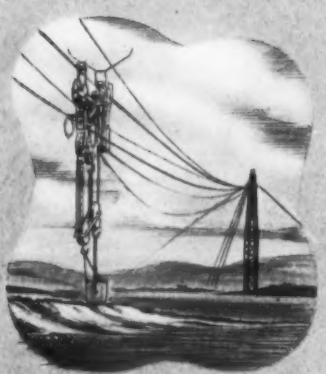

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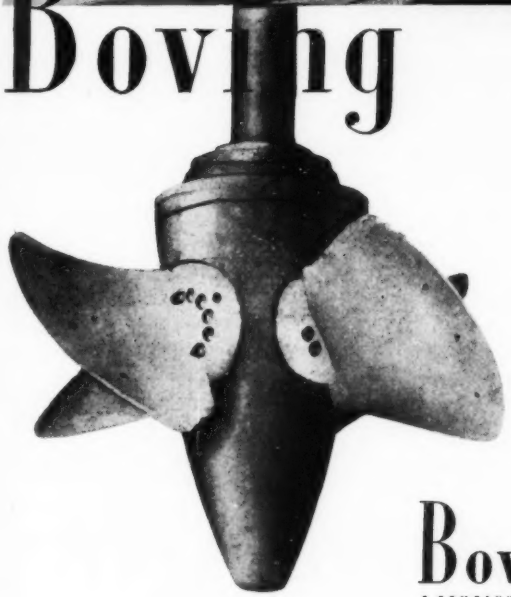

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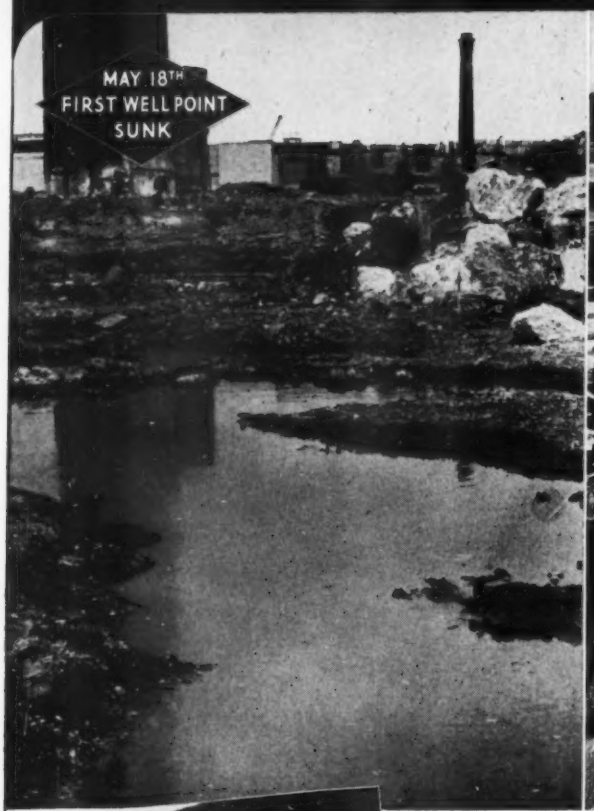

The task facing Blaw Knox on May 18th, 1949 was to reduce ground water to give dry conditions 13 feet below ground water level. In this single-stage installation which encircled the whole area to be excavated 340 wellpoints were jetted and four wellpoint pumps connected up to provide an optimum pumping capacity of 240,000 gallons per hour. By June 20th final excavation was well under way and on June 25th the first concrete was laid under completely dry conditions.

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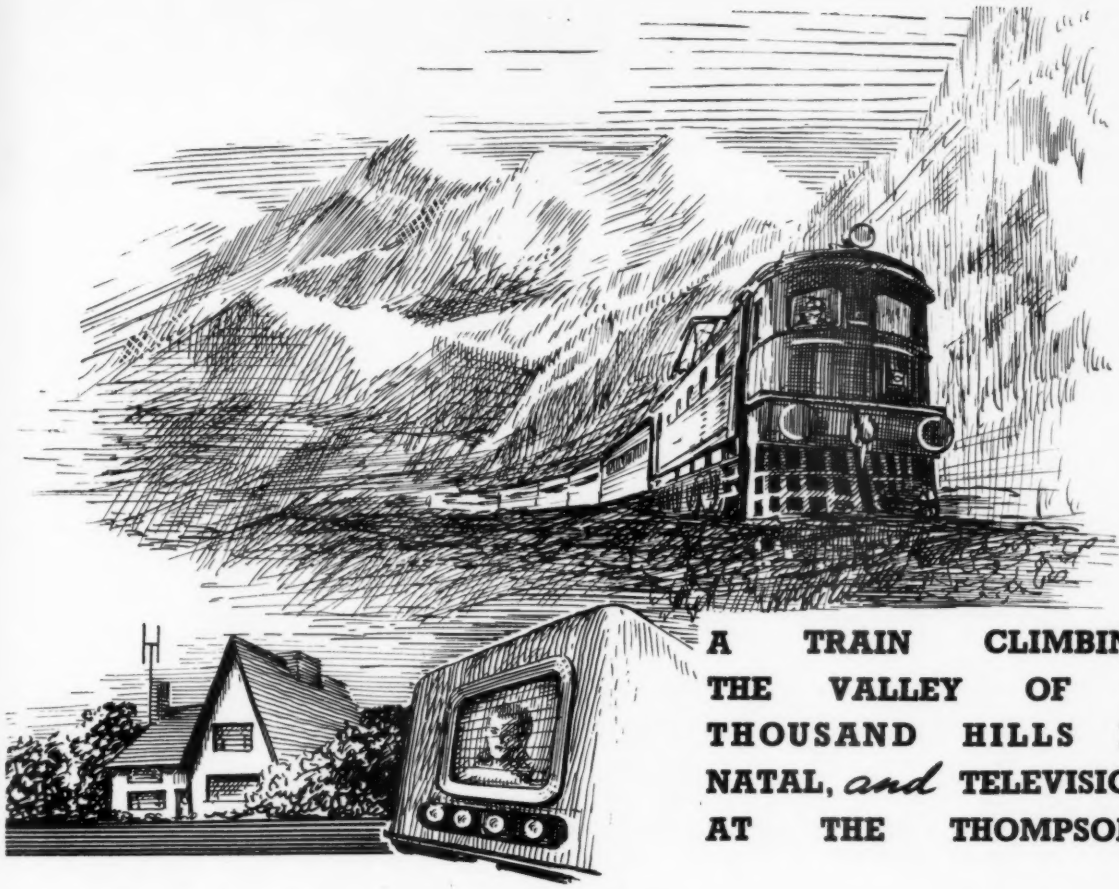

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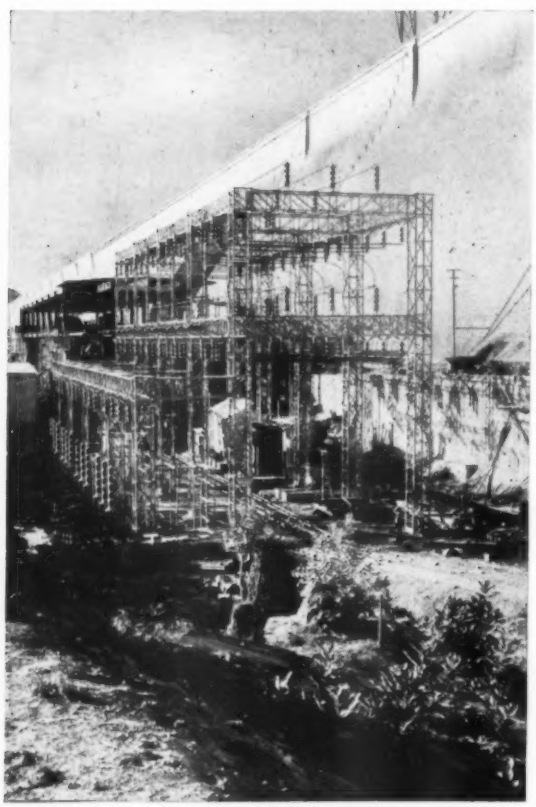

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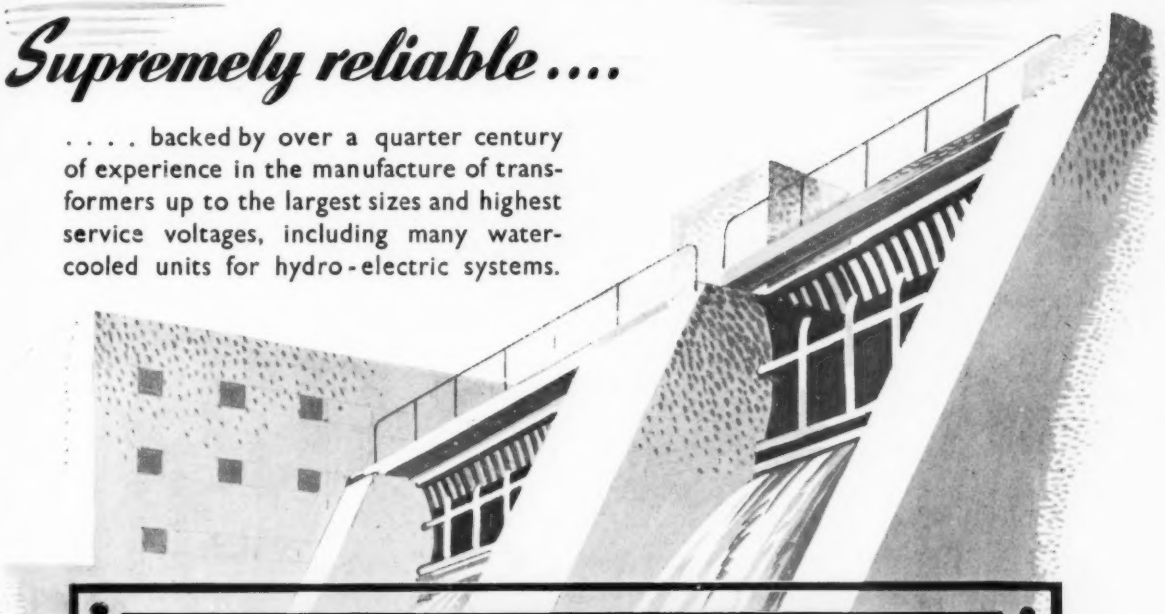

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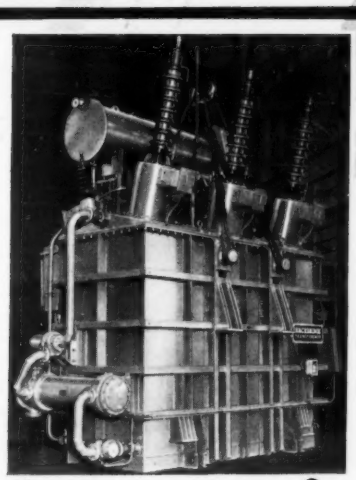

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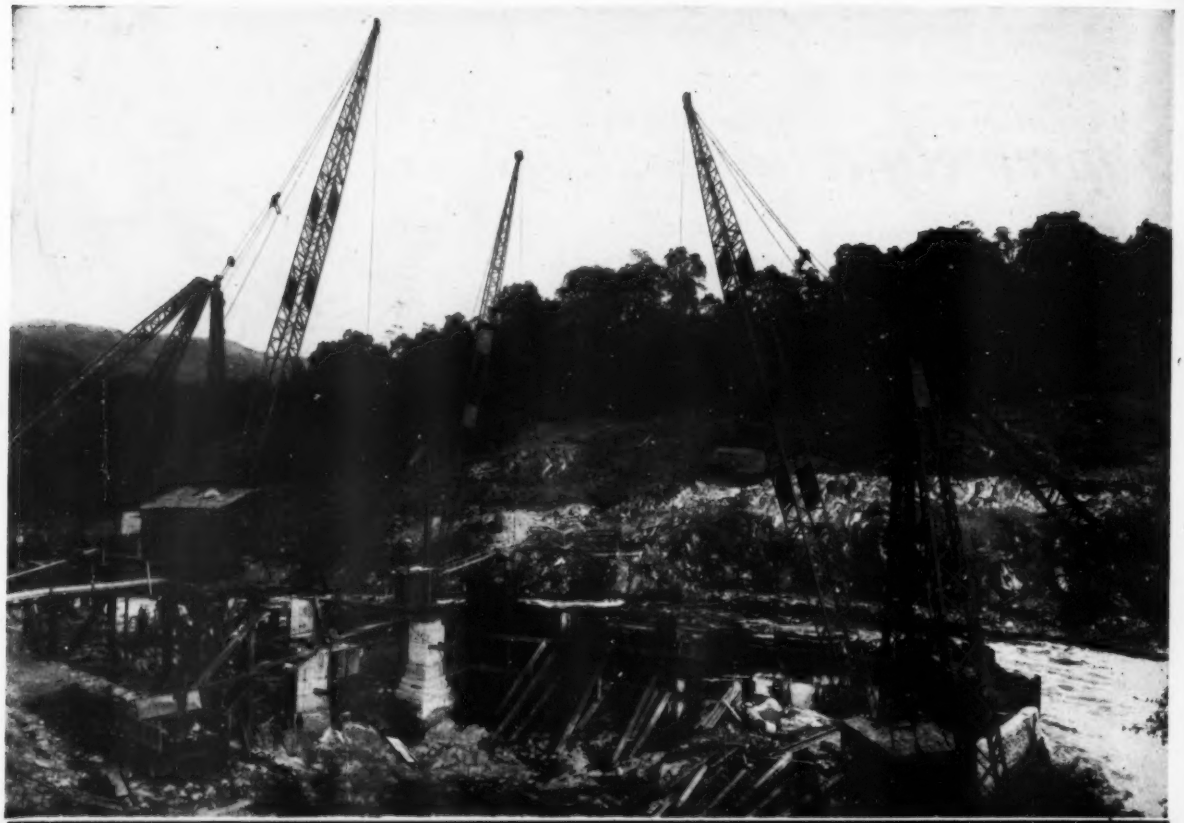

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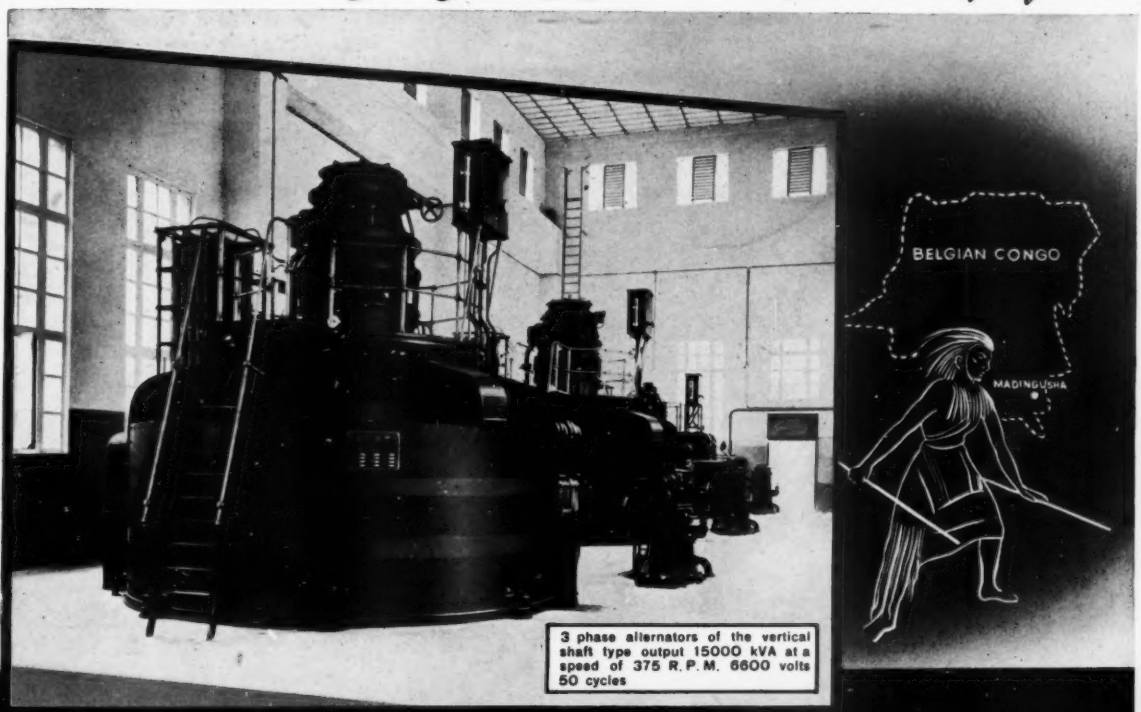

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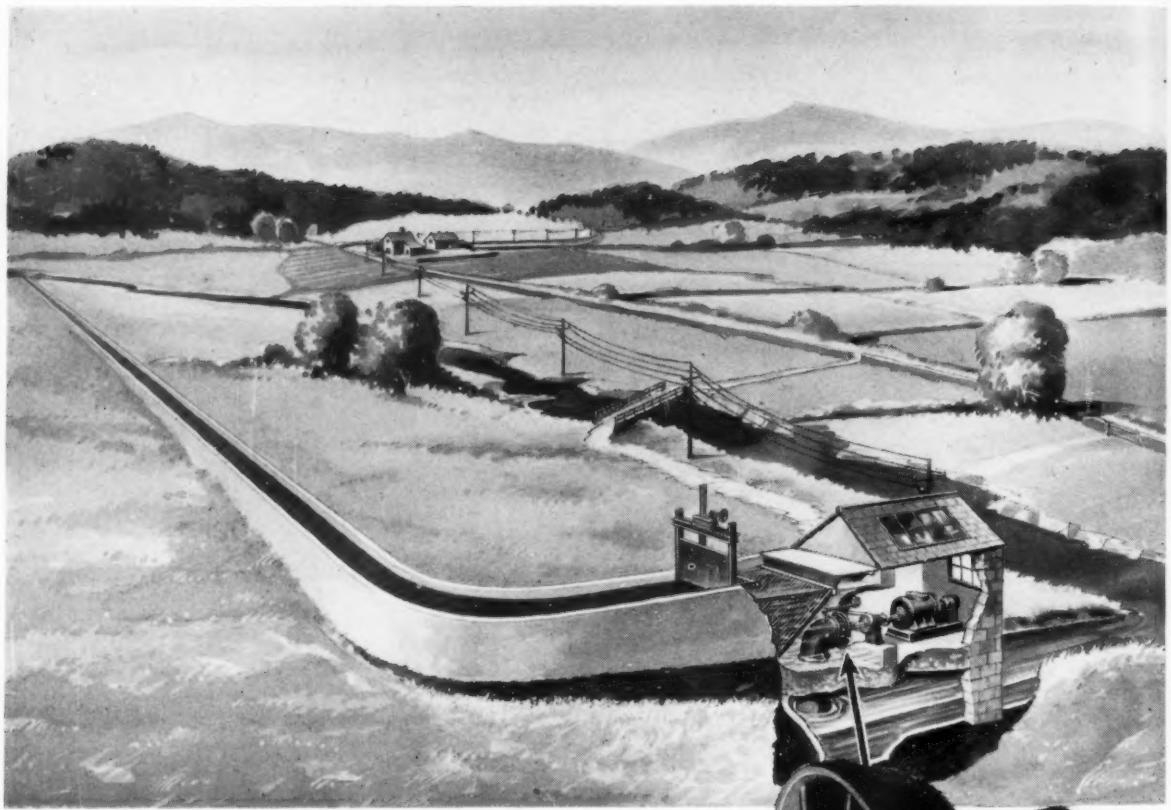

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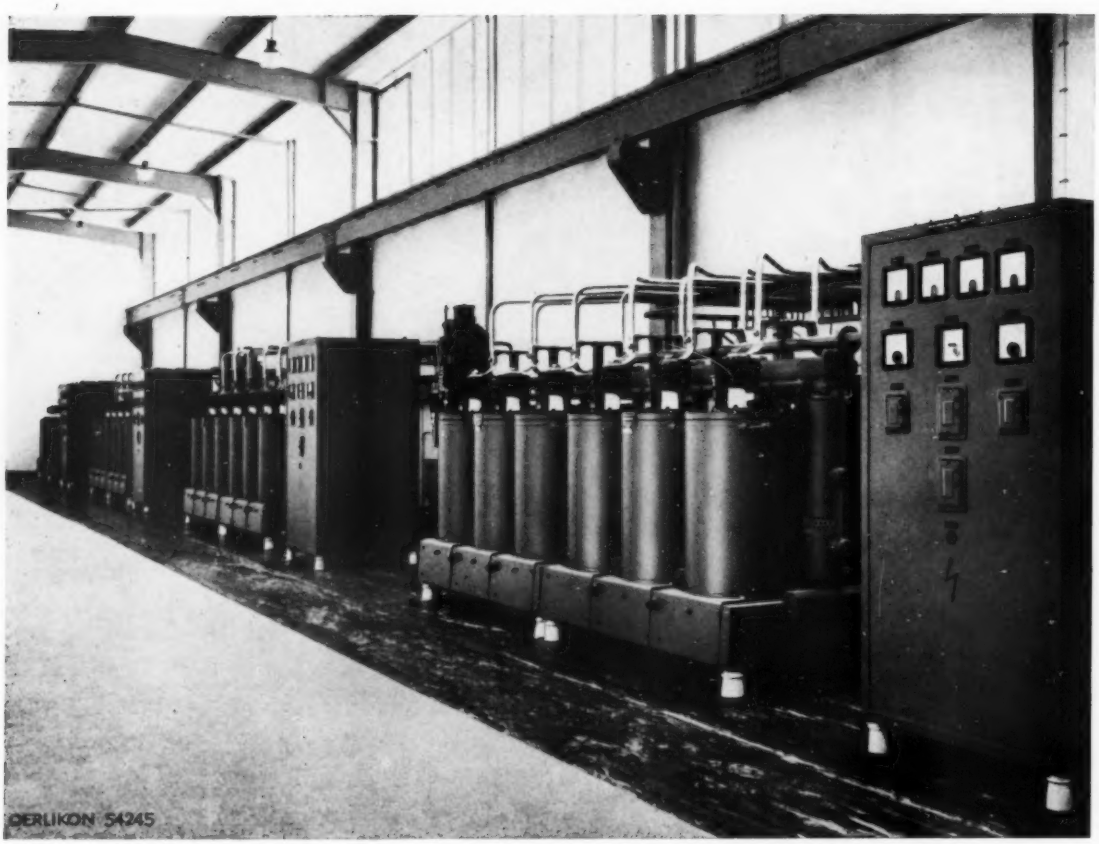

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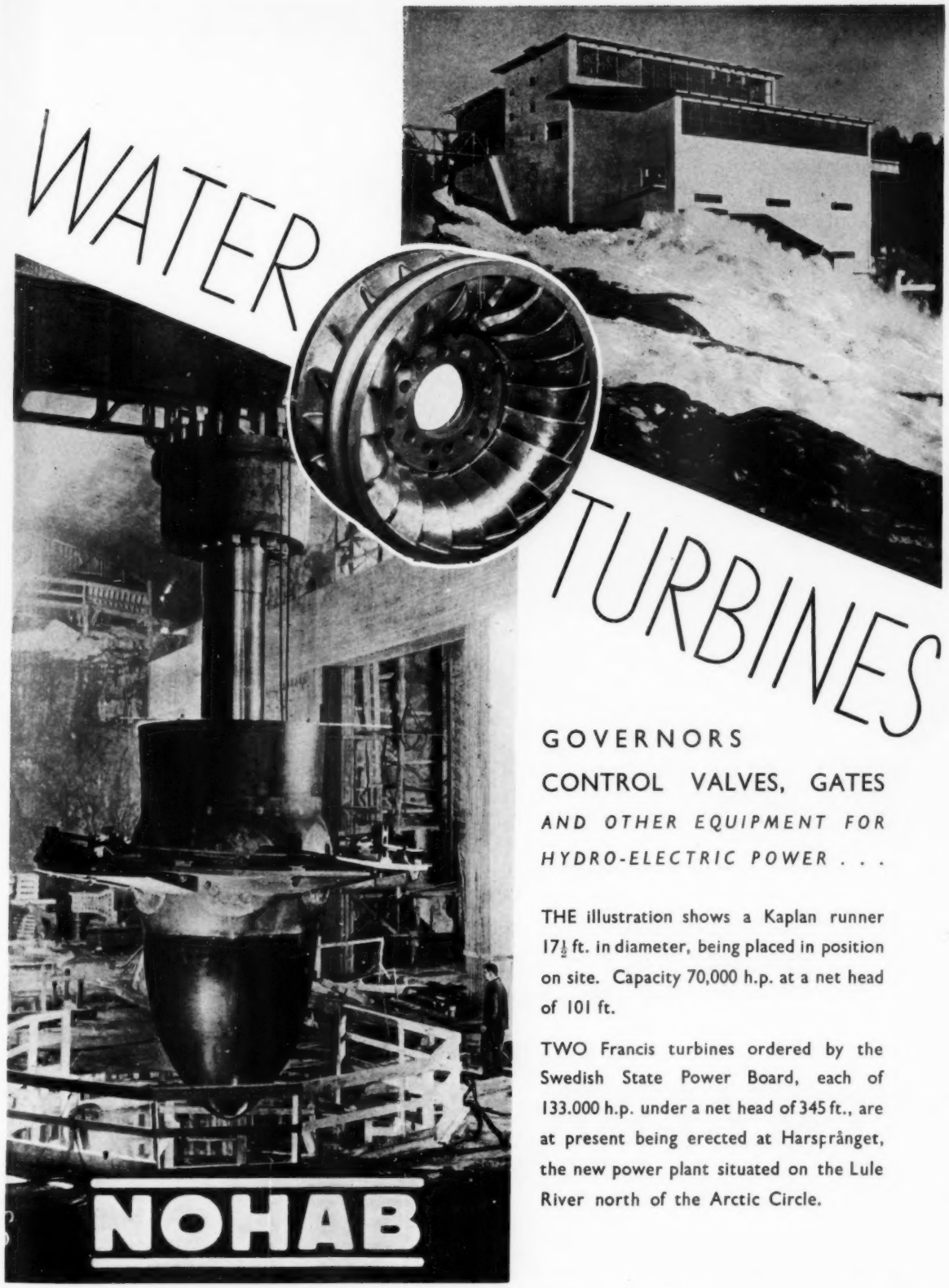

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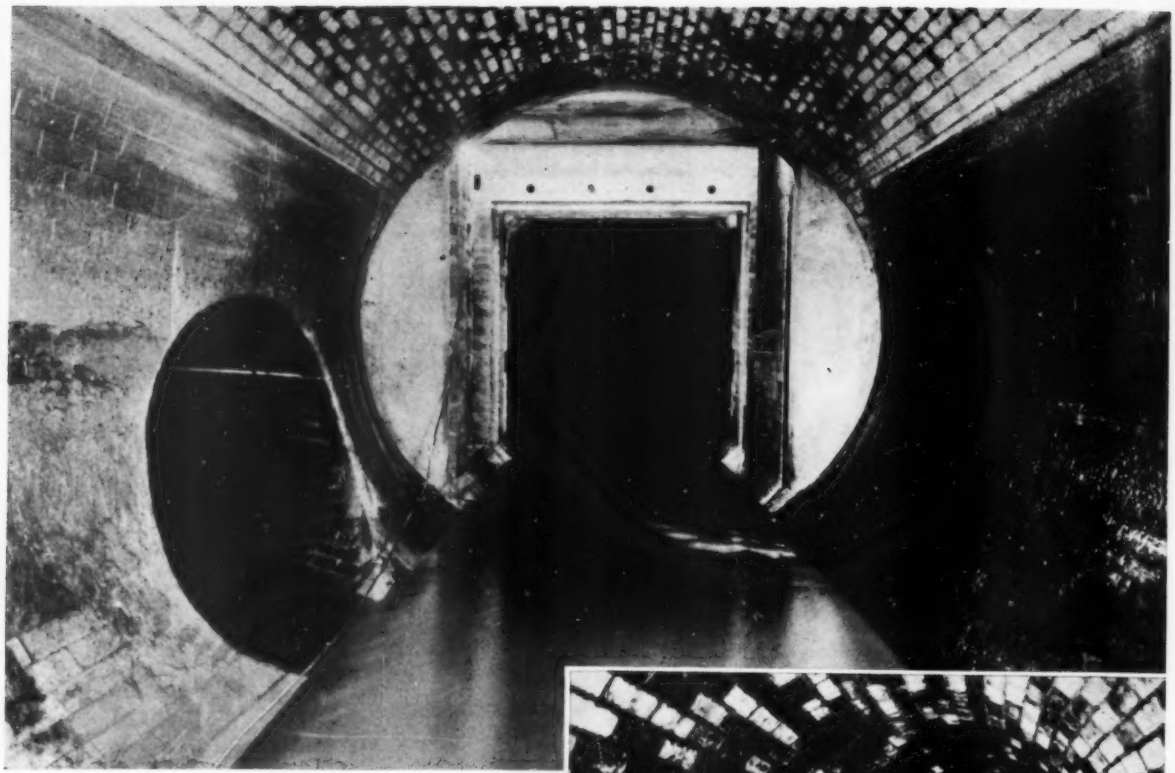
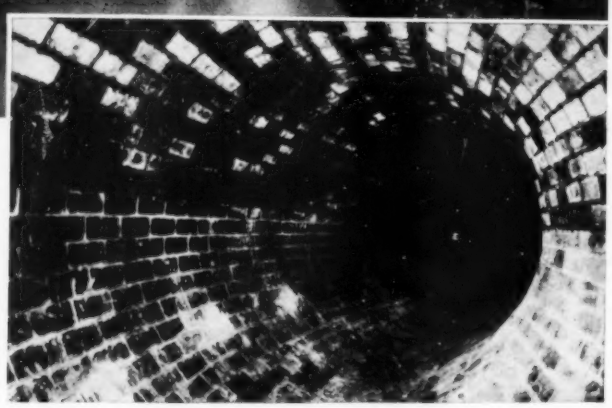


ABOVE: *Completed 10 foot Penstock Chamber looking downstream*



RIGHT: *Curve at upstream end of new sewer*

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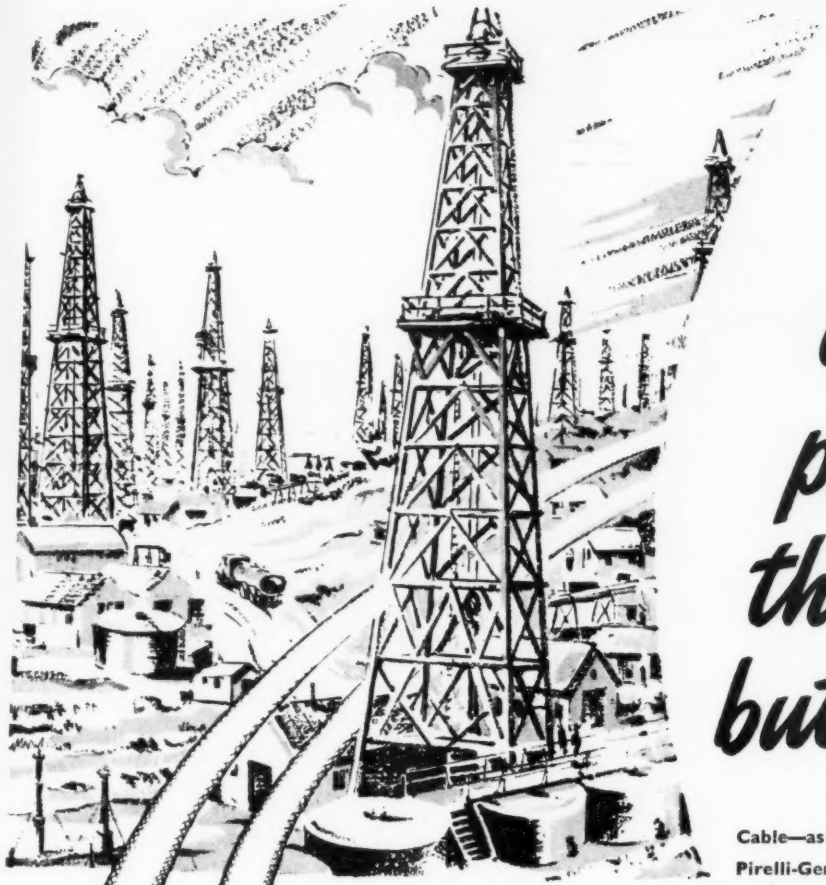

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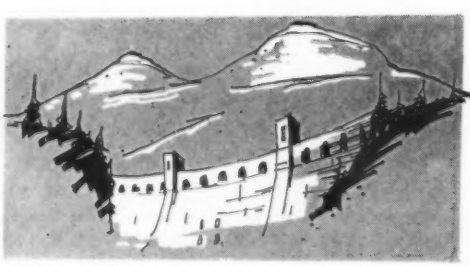

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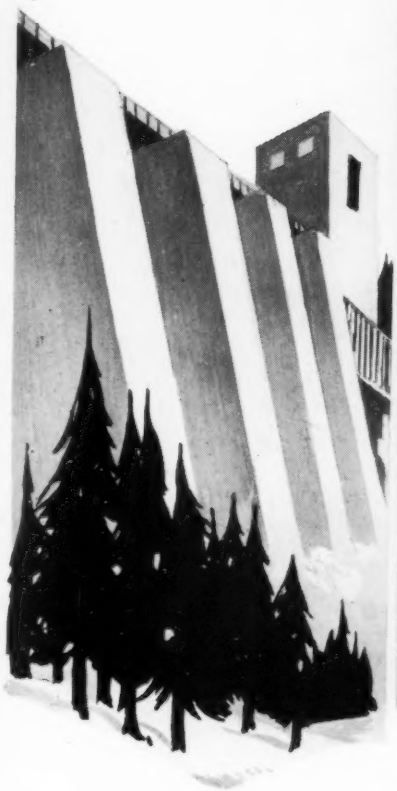

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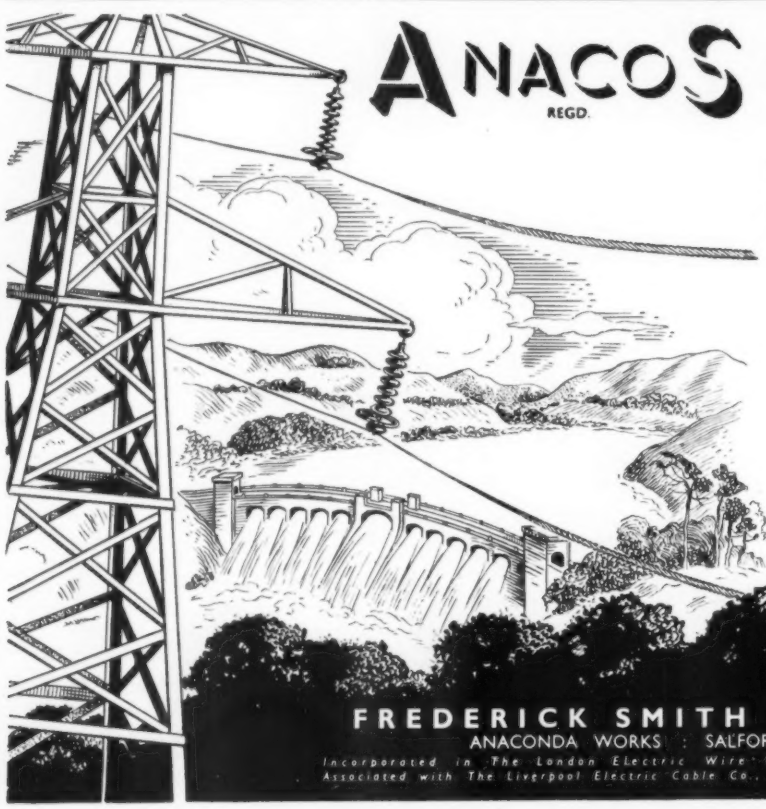

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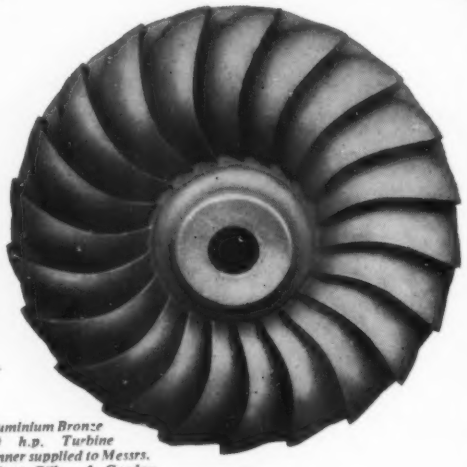

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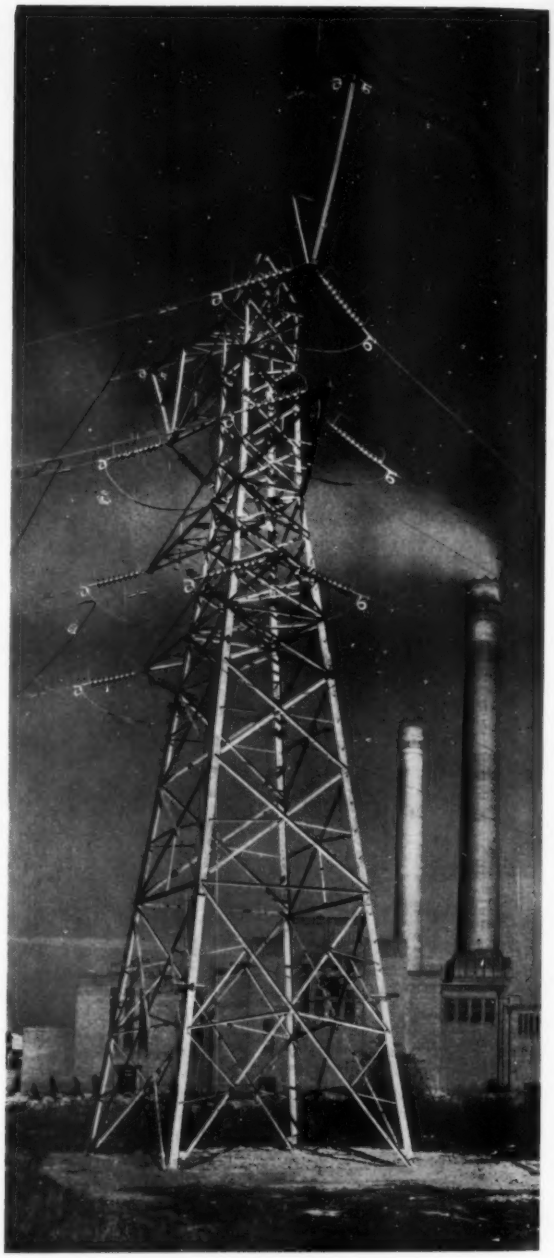

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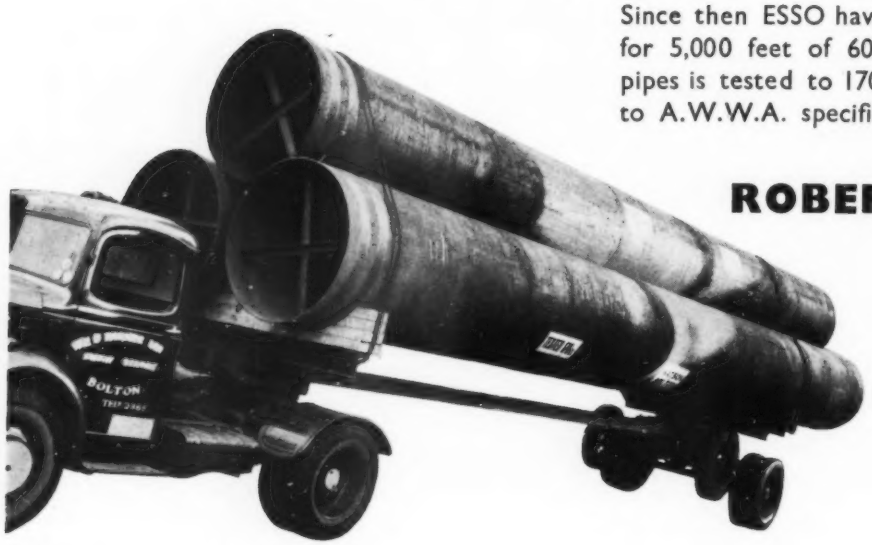

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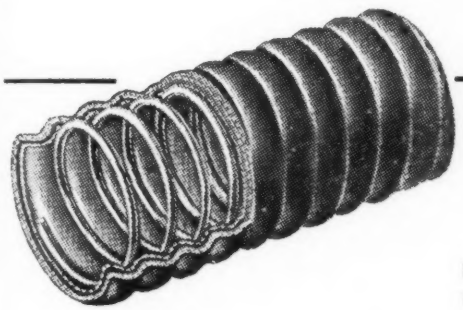

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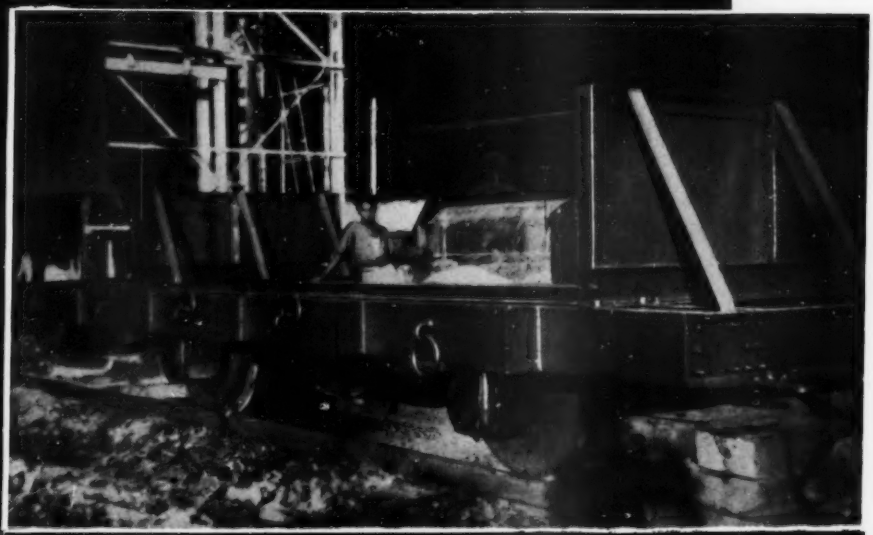

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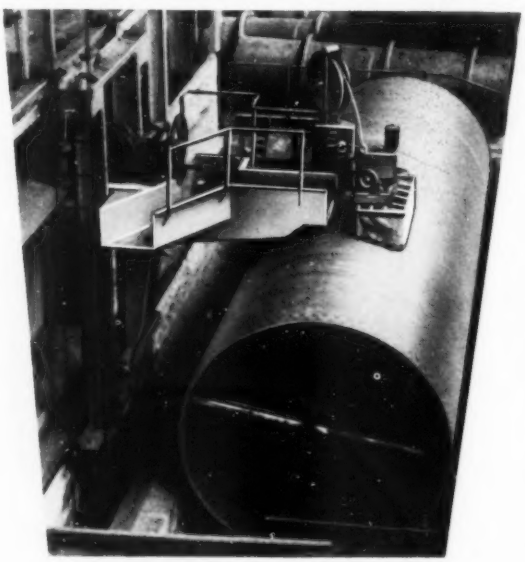

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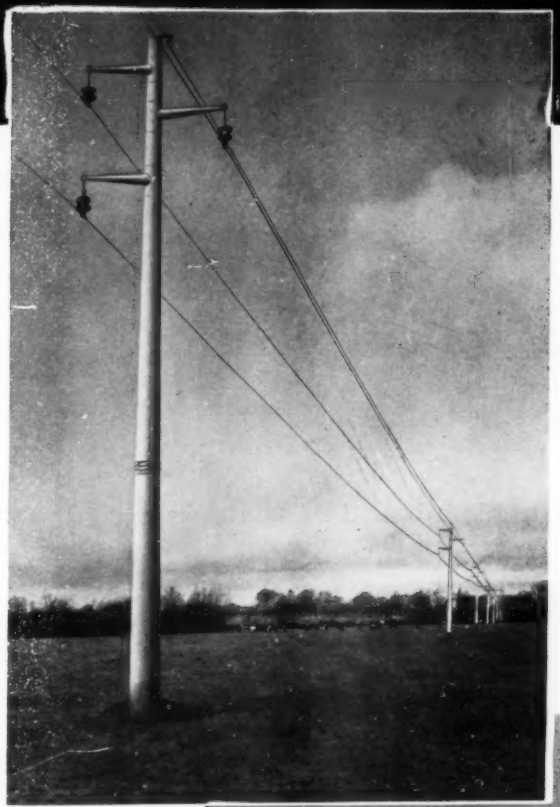

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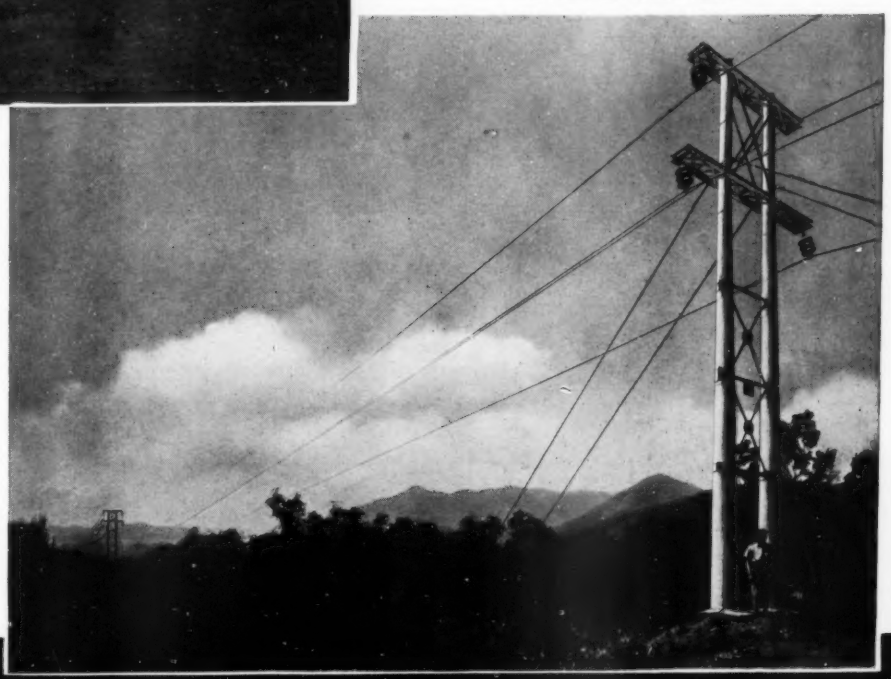

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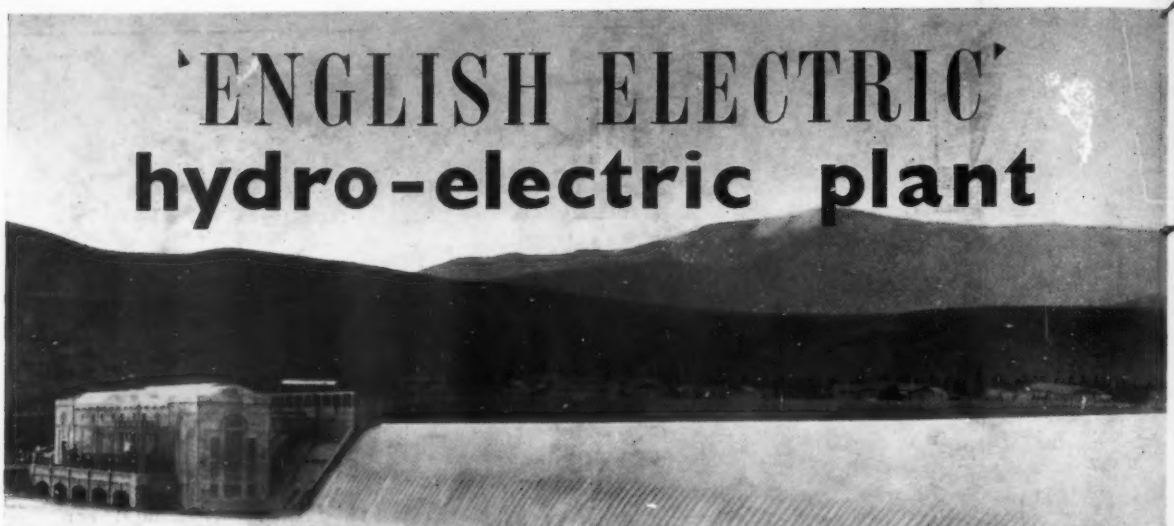
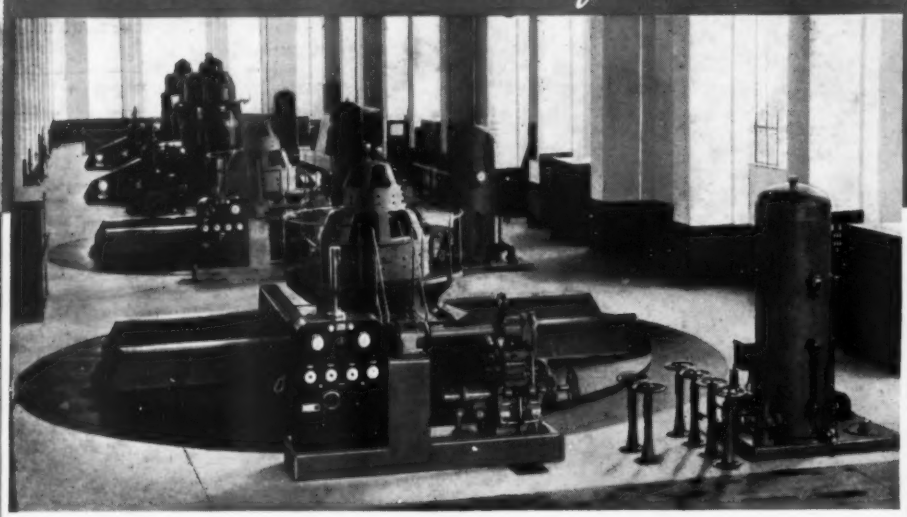


WAITAKI *New Zealand*



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